THESIS

EXAMINING THE RESPONSE OF WORLD WHEAT PRICES TO CLIMATIC AND MARKET DYNAMICS

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ABSTRACT

EXAMINING THE RESPONSE OF WORLD WHEAT PRICES TO CLIMATIC AND MARKET DYNAMICS

World wheat prices have fluctuated in recent years. Many factors affect wheat prices including; climate change, yields, oil prices, lagged prices and imports. In addition to gradually and consistently increasing global wheat demand, these market drivers are posited to impact world market equilibrium prices. To investigate how these factors differentially influence wheat prices, an economic analysis was conducted using a uniquely compiled data set of significant wheat producing areas and linear regression models. Key variables from five major wheat exporter countries/regions were compiled for the 1980 to 2013 time frame. The findings shared here update and support previous studies' conclusions and show that imports, oil price, and the previous years' price have a significant relationship with changes in the world wheat price. It is also found that the precipitation levels in the United States, and more broadly, reported yields in Canada, Former Soviet Union (FSU) and the United States, all have a significant correlation with world wheat prices.

DEDICATION

To my parents,
Ahmad and Vida,
And my amazing wife Mozhdeh,
For supporting me all the way.

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1. Introduction

The interface and tension between natural resources and food production systems due to perceptions of increasing scarcity of the former and the growing demand for the latter has fueled interest in analyses that can inform stakeholders on food market dynamics. Clearly, the demand for food grows with increases in both world population and the wealth of developing countries, whereas the supplies of natural resources are limited, or if renewable, increase only gradually. The tension between these market and resource systems is only heightened by concerns about how climate change may impact natural resource stocks and flows (when considering water). To explore one area where this relationship is of acute global interest, we can consider the food production systems that encompass questions of how food is produced, consumed and traded across a large share of the world's countries.

Grains are currently the most important contributor to human food supplies globally. About 21 percent of the world's food depends on annual wheat (*Triticum aestivum*) crop harvests (given relatively light stocks) (FAO.ORG, 2014). Developing countries consume 81 percent of total global wheat production, and most of these countries need to import wheat to meet their demand. In addition, wheat accounts for about 43 percent of food imported to developing countries (Oritz et al., 2008). Many of those countries pay subsidies to stabilize and/or lower food prices so that consumers can consistently meet their dietary needs, and thus, provide a better level of food security for households. Yet, world wheat prices have still been unstable in recent years so that global stakeholders have had to reconsider the effectiveness of their policies to support food security. Increasing world wheat prices have led to questions about the factors causing the current price instability.

On the demand side, increasing wheat consumption and subsequent market demand for wheat are likely drivers (ERS-USDA, 2015). Assuming constant or gradually increasing global supply, greater demand (and assumptions of faster growth on the demand side) will result in the market equilibrium forming at a higher price. Two billion global households use wheat directly as food; so, growth in demand for wheat usually occurs gradually and consistently as population increases. Another important factor that increases the pace of demand is growth of the middle class in highly populated developing countries, particularly those in the Asian region. More broadly, changes in lifestyle and consumption patterns result from an increase in wealth and cause an increase in demand for food, including grains. All of these factors increase the demand for wheat, and possibly, the volume of global trade that will occur to shift supplies to the regions of the world with the highest levels of increasing demand.

On the supply side, wheat production can also be influenced and impacted by many factors. Drought and oil prices are two such important factors. Climate change can influence food production in a variety of ways, as the climates of major production areas may change with respect to expanding season length, as well as increasing average temperature and average rainfall. For this study, we focus on how climate changes transform precipitation patterns as these changed patterns will likely affect world wheat production and trade. As one example, one recent drought event in a major wheat-producing country had substantial impacts on world prices (e.g. Australia 2007-08).

As another important driver, oil price influences the cost of inputs to wheat production and plays a major role in field operations as well. Wheat and oil price fluctuations have similar patterns that indicate high correlation between the two. Most fertilizers require petroleum or natural gas to be manufactured, and fuel is an important energy source on the farm and for transportation. Oil prices also indirectly affect wheat price through the secondary effect on biofuel production. When oil prices increase, demand for other types of fuel, like biofuels, shifts and result in increases in the price of substitute fuels like ethanol that can be both an alternative for gasoline (as a main oil product) or be added to it. This makes biofuel production more economically attractive; since maize is an important source of ethanol, the price of maize rises and more farmers decide to dedicate their land to planting maize. In short, biofuel crops such as maize are substituted in production systems in place of wheat, and wheat production decreases, which may explain some of the volatility and upward pressure in wheat prices. In addition, the European Union, the United States, and other major agriculture-producing countries have all been encouraging biofuels by applying production subsidies and placing orders to encourage farmers to plant energy crops in order to meet energy needs (or even policy-driven quotas for renewable fuels).

Fluctuations in and increases in the level of wheat prices in recent years exhibit a different pattern in the world wheat market when compared to earlier decades; the dynamics and influence of the factors discussed above are considered major contributors to these changes. Due to increases in world wheat prices, firms and countries need to pay more to import wheat, and subsequently, foods that depend on wheat become more expensive. In many developing countries, wheat and foods prepared with it are a major share of the citizenry’s diets; therefore, increases in wheat prices will have noticeable effects on the cost of food and standard of living.

Wheat-producing countries (and their agricultural sectors) also suffer because of price fluctuations. Decision-making can become difficult when farmers face price instability. Generally, uncertainty increases the risk of investments, and may trigger risk-averse people to avoid investment in the production process. This could potentially cause reductions in supply, and may lead to even higher prices in the international market, which further harms consumers. It is clearly a vicious cycle of downward supply pressure and increasing prices may result. Therefore, wheat price forecasting is very important to both consumers and producers.

Because wheat prices affect so many people, understanding how different factors affect the world wheat market is essential for policymakers. Understanding the market behavior and key factors that affect wheat prices helps industry and governments that do subsidize grain prices to manage budget allocations when faced with wheat price fluctuations. In a broader sense, a better understanding of the world wheat market also helps investors and traders improve their profits and reduce investment risks.

To investigate the causes of wheat price uncertainty, this thesis examines key factors affecting demand and production to specify which factors are most important, and the relative importance of each. A particular focus is placed on major supply regions and trading partners in this study. To assess these markets and dynamics, several sources of data on wheat markets and one climate change indicator (precipitation) were compiled and modeled in a linear regression model. The model is guided by the background on literature and on wheat markets that follows below. The model's results are then used to examine how wheat world price is affected by factors that are assumed to be most relevant, like oil price, previous year price, import, yield and precipitation. This study examines the hypothesis that each of these factors contribute significantly to world wheat price. Then, discussion will be used to investigate and infer the nature of these relationships. The thesis concludes with a discussion of market and policy implications of these findings, along with ideas for future research to further this analysis.

1.1 Wheat Market Fundamentals

This section discusses the basic tenets and trends related to international wheat trade and the factors that are assumed to affect world wheat prices. It then describes the properties of global wheat supply and the industry’s global production environment.

1.1.1 Trade

Trade is a kind of arbitrage between two different places: wheat is traded between countries that have production surpluses and high consuming countries. Global agricultural trade, including commodity flows, is affected by the growth and stability of world markets, including changes in world population, economic growth, and income. Other factors affecting agricultural trade are global supplies and prices, changes in exchange rates, government supports for agriculture, and trade protection policies (USDA, 2013).

Changes in supply and demand shifters over time have led to subsequent changes in wheat trade. Supply shifters include technology, production yield, climate and weather changes and availability of cultivated land. The demand shifters include both overall population growth and the changes in a population’s taste and income. Government policies and currency exchange rates can shift both supply and demand.

First we can focus on factors that influence wheat trade by shifting the supply. Technology has affected supply through development of more efficient transportation and farm machinery. Modern transportation infrastructure has helped reduce the cost of wheat transportation, and particularly, regional and international trade. In addition, contemporary planting methods using advanced farm machinery, along with plant breeding, have increased yield per hectare; increasing the supply of wheat and reducing its price through lowering costs of production. Although wheat breeding and seed innovation has lagged behind those impacting maize and soy systems, there have still been notable increases in yields and losses due to pest pressures (Chakraborty, 2011)

As with other crops, weather is also one of the important factors influencing levels and stability of wheat production. Short term weather variations like drought and floods, as well as long term climate changes like global warming, affect many wheat-producing regions of the world. This can change the quantity of wheat produced in different regions differentially, and therefore, change the quantity of wheat traded between countries. Plant diseases and pest pressures can also be influenced by climate change implications, and thus, affect wheat production and trade in a similar way.

On the other hand, several factors affect wheat trade by shifting demand. Population is one of the most important factors that affect demand. Increases in population raise demand gradually, but constantly, and perhaps, differentially across regions. The changing tastes and income of the population can also affect demand through changes in population, dietary changes as countries economically develop and wheat consumption patterns.

Government policies and currency exchange rates can influence international wheat trade by shifting both supply and demand. World wheat trade has formed because the dominant regions for wheat production do not match regions where consumption occurs spatially. Governments use various policies such as subsidies, taxes and tariffs to provide food security for their people and these policies can affect the world market in many ways. Typically, governments of wheat producing countries support their farmers by imposing import tariffs and limiting wheat imports. On the other hand, governments of wheat importing countries sometimes support their consumers by imposing subsidies that make wheat more affordable for the consumers. Both strategies clearly have implications for trade flows.

Currency exchange rates are important in international trade between countries that use different currencies. For example, when wheat is traded in US dollars, if the exchange rate converting US dollars to the Euro decreases, wheat will become relatively less expensive in Euros and this could change the market equilibrium of world price. Similarly, differences between inflation rates of countries can potentially influence the trade between them. Moreover, inflation directly affects wheat production costs and prices because of the pressure on the producer price index that growers face.

With new farming technologies, wheat production has become a capital-intensive process that needs different types of machinery for pre-planting, planting, harvesting and transportation. The cost of all of those processes is directly affected by oil prices, and more broadly, energy costs, which is a complementary good to machinery and itself an input to wheat production. Oil is also used in the production of fertilizers and other crop production applications that are additional inputs to wheat production.

1.2.2 Wheat

Wheat (*Triticum aestivum)* is one of the principal cereal grains that is produced and consumed globally. It is grown on more land area than any other commercial crop, and continues to be the most important food grain source for humans (Curtis et al., 2002). World wheat production is ranked third in weight produced, after corn and rice (USDA, 2014). This is likely due to that fact that wheat can be cultivated in many areas with many different types of weather, elevation, or soil. It is mostly cultivated between the latitudes of 30°N to 60°N and 27°S to 40°S (Nuttonson, 1955), more than 3000 meters above sea level, and in places with temperatures between 3° and 32° Celsius. Wheat is adapted to a broad range of moisture conditions from dry weather to seaside moisture. Although about three-fourths of the land area where wheat is grown receives an average of 375 to 875 mm of annual precipitation, wheat can be grown to some degree in most locations where precipitation ranges from 250 to 1750 mm (Leonard and Martin, 1963). Wheat production covers more than 240 million hectares globally, larger than for any other crop, and its gross world trade is greater than all other crops combined (Curtis et al., 2002). Wheat is a major food staple because of the wheat plant's agronomic adaptability; ease of grain storage; and ease of converting grain into flour for making a number of staple food products. Wheat is the major source of carbohydrates in the diet of many countries; such as Pakistan, Iraq and Egypt. (Fig. 1)

Wheat production increased sharply in the 1960's and gradually afterwards, mostly as a result of higher yields per hectare, in a technology shift commonly labeled the "green revolution" (FAO, 2003). Through research and development, the green revolution resulted in the development of rust-resistant semidwarf wheat that could utilize large amounts of nitrogen fertilizer and had a higher yield. Between 1980 and 2013, the world's annual harvested area of wheat decreased by 0.24% and the yield increased by 1.41% (FAO, 2014). Average annual world yields increased from 1855 kilograms per hectare (kg/ha) in 1980 to 3264 kg/ha in 2013 (FAOSTAT, 2014).

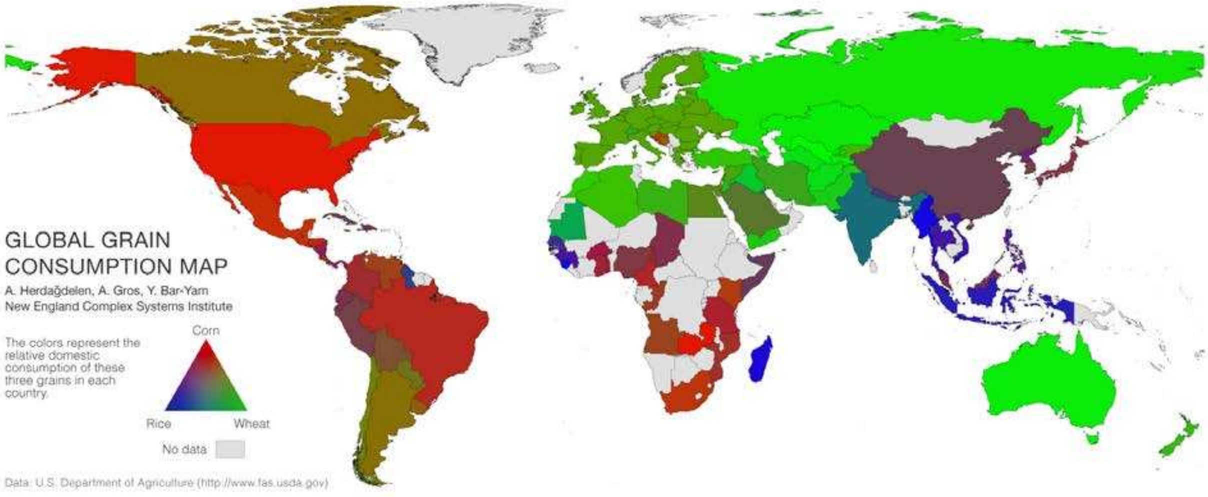


Figure 1 – Global 3 major grain consumption map (New England Complex Systems Institute)

Most wheat is consumed within the country where it is produced; still, roughly one-fifth of the global annual production is exported. World wheat trade was estimated at 148 million tons in 2011, most of which was imported by developing countries. Despite the increase in wheat production over the couple of past decades, developing countries continued to import two-thirds of all world wheat trade flows (FAO, 2014).

2. Literature review

Studies considering the effect of global weather changes, oil prices, and imports on wheat prices simultaneously, are quite rare, especially research that considers the relationship between precipitation and wheat price on a global scale. Such a simultaneous analysis can provide a richer long-term projection view of the problem, but almost all studies relating to this topic consider the effect of just one of these factors at a time on wheat price. Most recently, much attention was paid to relationships between climate and markets after the world wheat price fluctuations that happened in the years following the 2008 economic crisis (figure 2.1).

Figure 2.1 Wheat price change during 1982 to 2013, based on FAO data

2.1 Weather

A large body of literature exists on climate change and its effect on agricultural production with respect to yields and weather forecasts including Meza (2009), Ubilava (2014), Brisson et al (2010), and Asseng (2010). Most of these studies focus on domestic agriculture across different countries. Some other studies have investigated the effect of oil price as an important element in crop production and changes in agricultural commodity prices including Saghaian (2010), Esmaeili (2011), and Natanelov et al (2011). And some studies have tried to find the influence of the previous year's prices on the market, since, like other economic areas, farmers and governments are continuously responding to price changes (Dorosh et al (2002); Sekhar (2003)).

Weather is an important factor in agricultural supplies because agriculture is a climate-sensitive sector. Besides production difficulties, global migration, economic disruption and land use change are the other key factors of changes in food production (Liverman, 1987). Overall, climate change and the greenhouse effect have positive effects on production in areas above 55° latitude, while they have negative impacts of drought and extreme heat, and therefore, reduce production in many countries within the latitudes where the majority of wheat consumers currently live (Valizadeh et al., 2014). In addition to population and wealth, drought increases the demand for wheat imports in high-consumption regions by reducing local and domestic production. In recent years, Africa and the Middle East have imported about 45 percent of global wheat trade flows, and are predicted to have increases in aridity in coming decades that may drive further import needs (Dai, 2011). Drought is one of the greatest weather risks to agriculture in arid and semi-arid areas; since it decreases domestic wheat production, drought increases the demand for wheat imports. Arid and semi-arid regions account for approximately 30 percent of world total area and 20 percent of total world population, many of whom are wheat consumers (Sivakumar et al, 2005).

Climate change has various effects on wheat-producing countries. Global warming may be beneficial to wheat production in some regions, but reduces productivity in areas that are do not tend to have optimal growing conditions (Ortiz et al., 2008). However, global warming could potentially make cold regions warmer and more suitable for wheat production. Beyond climate change potentially shifting optimal production zones, temperature and precipitation changes may also impact producers through increased competition between crops and weeds, increases in plant diseases, and changes in soil nutrients. All of the above factors could change production costs (Kane et al., 1992). Some studies, like Izaurrald et al. (2003) and Zhang and Liu (2005), show increases in wheat yields in the American Northern Plains and China, respectively, while others forecast decreases in future production in regions like southern Australia (Luo et al., 2005).

International commodity markets operate and adapt given fundamental ratios of supply and demand growth, but stocks can provide a buffer when ratios change significantly and disrupt historical trade patterns. Several years of drought, including those in Europe in 2006, North America in 2006-2007, and a severe drought in Australia from 2006-2008, have driven wheat stocks down to critical lows. This, coupled with the surge in bio-fuel demand, has created record grain prices (McCalla, 2009) that make the scarcity of buffer stocks a concern to those who seek to stabilize world food prices. In this study, precipitation in producing countries is considered as a parameter, since it influences wheat production and world wheat prices.

2.2 Oil

Oil is another one of the primary factors that affect agricultural commodity prices (Jebabli et al, 2014; Sadorsky, 2014). It affects wheat price in two aspects: first, as a production input; and second, indirectly through demand for biofuels and resulting substitution effects. The prices of fertilizer, farm machinery, and transportation are also affected by the crude oil price directly. With high oil prices, demand for biofuel increases and agricultural inputs such as land are dedicated to planting energy crops such as corn. Therefore, wheat production is highly correlated with oil prices (Chen et al., 2010).

Saghaian (2010) studied the interconnections of agriculture and energy markets. The linkages within the causal structure of oil, ethanol, and corn were investigated to find how instability is transferred from energy markets to agricultural markets. Contemporary time-series analysis was done and Granger causality was supplemented by a directed graph theory modeling approach to identify the causal structures among energy and commodity variables. Saghaian demonstrated a strong correlation among oil and commodity prices, but the evidence for a causal link from oil to commodity prices was unclear.

Esmaeili (2011) also focuses on the co-movement of food prices and a macroeconomic index, focused particularly on oil prices. The study investigated the food prices of seven major agricultural products and microeconomic variables. A screen test and the proportion of variance method were used to determine the optimal number of common factors. The study concludes that the food production index has the most influence on the macroeconomic index and that the oil price index has an influence on the food production index. So, crude oil prices have an indirect effect on food prices.

Natanelov et al. (2011) more specifically studied price correlations between crude oil futures and a series of agricultural commodities and gold futures. The study applied a comparative framework, various co-integrations and causality tests to identify changes in relationships between these price levels through time. The study discovered that mature and well-established commodity futures markets display co-movement with crude oil prices in the long run.

All studies indicate significant correlations between agricultural commodities and crude oil prices, especially for corn which is the primary source of ethanol production. As mentioned before, corn is an alternative crop in many production systems as a substitute for wheat, and therefore, oil price indirectly affects wheat price.

2.3 Past year’s price

To find a pattern and predict the future, we commonly use past years’ price information and trends in analysis of market prices. Like other industries, agricultural suppliers respond to price by increasing or decreasing production. But, due to the nature of agricultural processes, these responses take a longer time to be revealed. Wheat, like other annual grain crops, has this lag and responds to the previous year’s price (Chand, 2007). Previous year’s price and lagged responses are traditionally explained with the Cobweb theory. Cobweb theory is an economic model that assumes crop production plans are based on a time lag between supply and demand decisions (Pashigian, 2008).Cobweb theory applies to agricultural production markets because of the natural lag between production decisions and the actual supply of goods to the market. This lag can result in large enough price fluctuations that there is a potential issue in maintaining food security within developing countries. It can cause particular problems for cereals that are the main portion of population diet in these countries. As a result, some governments, like India, try to prevent such fluctuation by putting minimum support prices for commodities. This price floor is justified as making production decisions based on the previous year's prices easier for farmers (Tripathi, 2009)

All in all, the previous year's price is always a strong basis in producers' decisions related to future production and is considered an important factor in wheat price forecasting.

2.4 Trade

Wheat consumption has grown as the population has increased and as a result of increases in wheat production, its trade has grown over the past few decades. Wheat is purchased for two main purposes, consumption and creating stocks as a buffer. The consumption share can be used as both human food or for an input to animal feeding. Wheat consumption has increased by 1.6 percent annually, on average, during the past three decades (FAOSTAT, 2015). As mentioned earlier, stockpiling is a way to create an intertemporal buffer against shortage for large wheat consumption periods or low production years.

Wheat trade faces many policies and regulations that change over time. Subsidies, tariffs, and quantity restrictions are some of restrictive policies that prevent the market from functioning in a free trade manner. For example, the United States and European Union, two of the largest exporters in the world, set subsidies for wheat exports so that their producers can sell wheat at lower prices and stay competitive in the international market. Likewise, many countries try to protect farmers and domestic producers from low international prices by limiting market access.

To eliminate market distortions, many trade agreements force countries to reduce tariffs and open the market to international free trade. But such agreements are not fully successful or effective because countries try to limit imports by non-tariffs barriers instead, including the imposition of import licenses and quality restrictions (Hertel et al, 2010; Frieden, 1996).

Import tariff policies vary in different countries. In some major importing countries, like Egypt, there are high tariffs on wheat products and this has resulted in increases of wheat grain imports. These countries typically have a higher tariff on processed wheat products like pasta or bakery products. But in some countries the opposite is true and value added products that contain wheat have a lower tariff than those placed on wheat grain. For example, in Kenya, import tariffs for wheat flour are less than those imposed on wheat grain (Ackello-Ogutu, 1997; Aksoy, 2005).

The other issue in the wheat world market is the effects of food aid or assistance programs. Most of these programs are donations from major world wheat exporters to developing countries, and are aimed to fight famine, but can indirectly affect the world wheat price if they modify demand. (Figure 2.2)

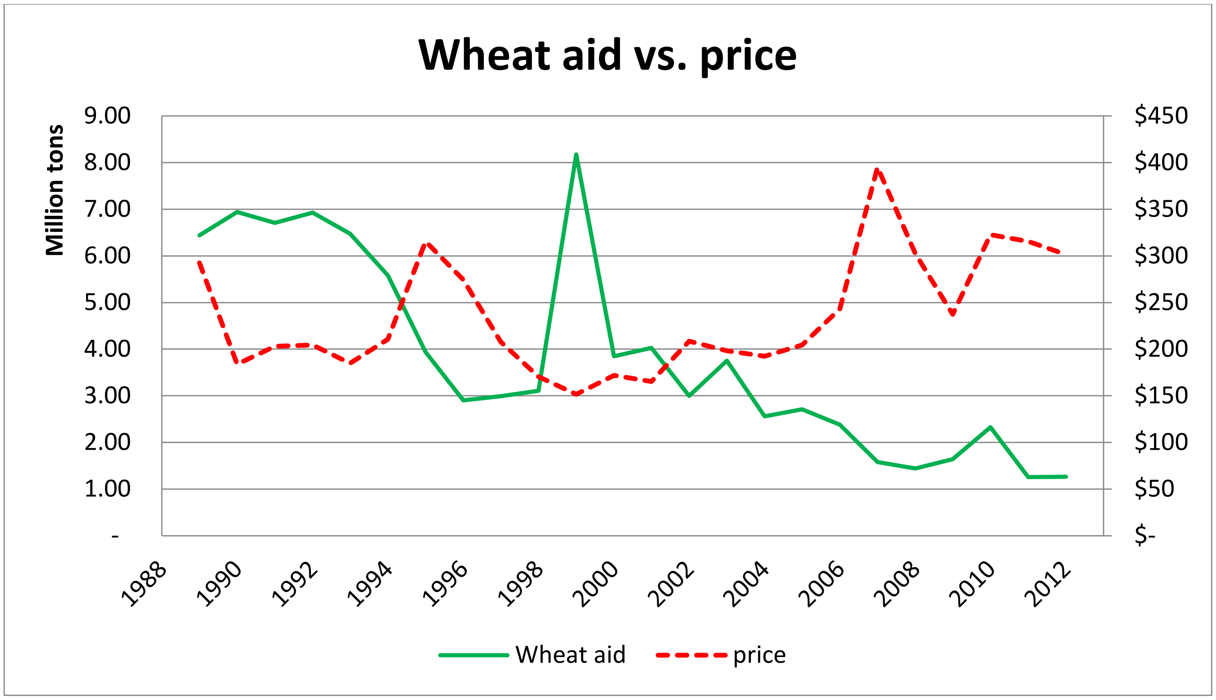


Figure 2.2 Wheat aid vs. wheat price. Data from World Food Program and OECD
Wheat aid is total of wheat and wheat flour that provided and wheat prices deflated in terms of 2013 dollars between 1989 and 2012

It should be noted that wheat trade does not have a simple geographic pattern since many countries are both exporters and importers of wheat. The trade pattern also changes over time, as the quantity of wheat production, imports and exports in different countries change and world prices drive secondary shocks in the market.

Stock-to-use ratio is the other indicator that affects the world grain market; it is especially likely to drive a large price spike. It simply measures the interrelationship between supply and demand by dividing the ending stock to the total use (Bobenrieth et al., 2012). Low stock-to-use ratio (SUR) leads to a higher market price, because low stocks reflect a scarcity. This indicator has certain correlations between stock to ratio and crops' prices, but it's weak in explaining long term correlations (Daugherty, 2014).

2.5 Supply in Major Wheat-Exporting Countries

Based on USDA statistics, the five largest wheat exporting regions between 1980 and 2013 are the United States, the European Union (an alliance of 27 countries), Canada, Australia, and the Former Soviet Union (FSU), with 30.9, 30.2, 17.9, 13.5, and 9.8 million metric tons (MMT) of average annual wheat exports, respectively (FAO, 2014). During this 34-year timeframe overall trade flows increased, despite rises and falls in quantity of wheat exported due to weather, policies, wheat world price, and other factors. The following narrative presents a closer look at each key wheat-exporting country.

2.5.1 United States

Wheat production and yield levels in the United States remained relatively stable during the 34 years from 1980 to 2013. It seems that the world wheat price influenced the amount of wheat acreage and overall production in the U.S. Wheat yields have increased, but, due to decreases in the harvested area, the total production has declined by an average of 0.48% annually (FAO, 2014).

The United States was the largest exporter for almost all of the 34 year period, with a marginal advance from the second largest exporter, the European Union (FAO, 2015). In some years, like 1994 and 2008, the U.S. produced 10 percent of all wheat production in the world (USDA, 2015). In 2001, for instance, about 48.6 million acres were planted with wheat in the U.S. (USDA, 2015) and about 50% of the wheat produced was exported at a value of $9 billion (VOA, 2013). In the U.S., winter wheat is planted from the first of September through the end of October. In the southern states, harvest begins by the end of May and proceeds moving north, across the central U.S. wheat belt, by late August. The major growing areas for hard red winter wheat are located in the mid-west, centering on Kansas. Kansas and North Dakota are the largest wheat producing states in the U.S.: for example, 10.4 million metric tons of wheat was harvested in Kansas in 2012 alone. (USDA, 2014).

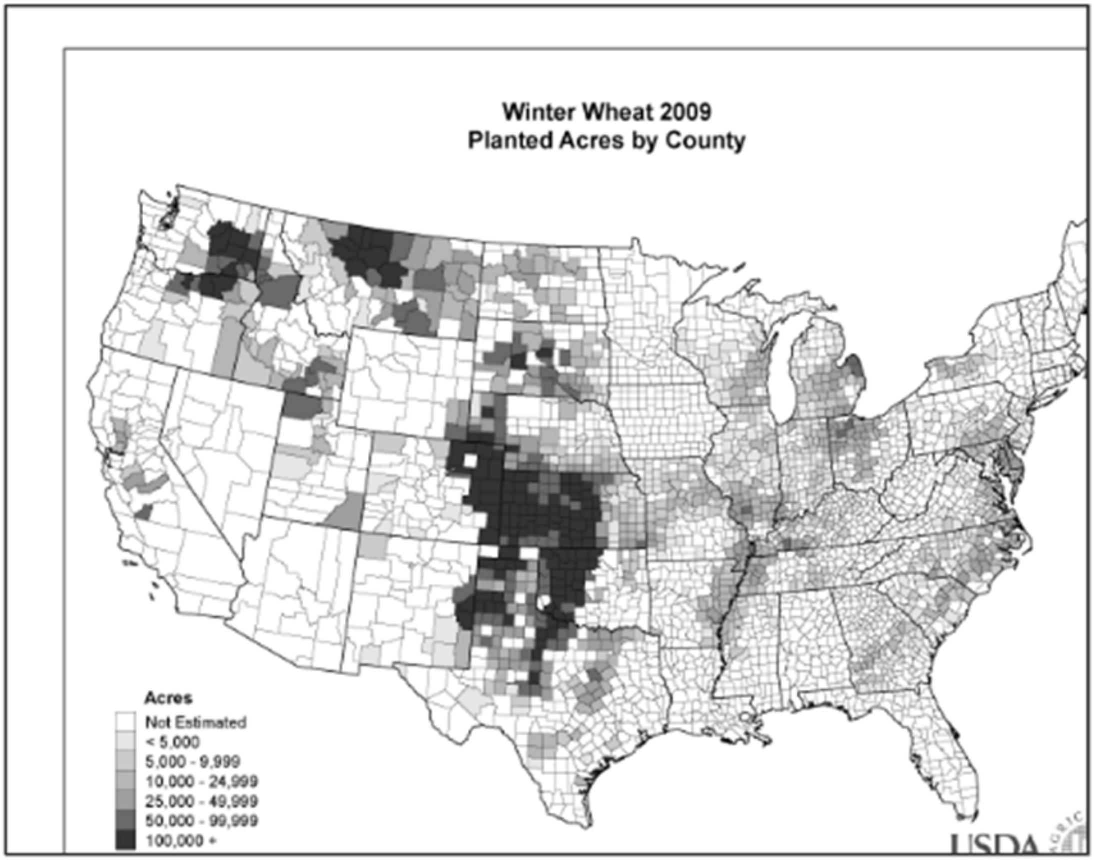


Figure 2.3 United States wheat production map

2.5.2The European Union

The European Union, which includes 27 countries (EU27), was the second-highest wheat producing region between 1980 and 2013. The average total wheat-planted land area in this region has increased by an average of 500,000 hectares every year over that period. In 2013, 26 million hectares were planted and 139 million tons were harvested (USDA, 2014). France, Germany, and Romania are the top three wheat exporters of the European Union with 66, 15 and 5.2 percent of the total wheat exports, respectively. France has the highest yield, with an average of 7.5 kg per ha (World Bank, 2014). The administrative region, Centre, leads the production of wheat in France (USDA, 2014).

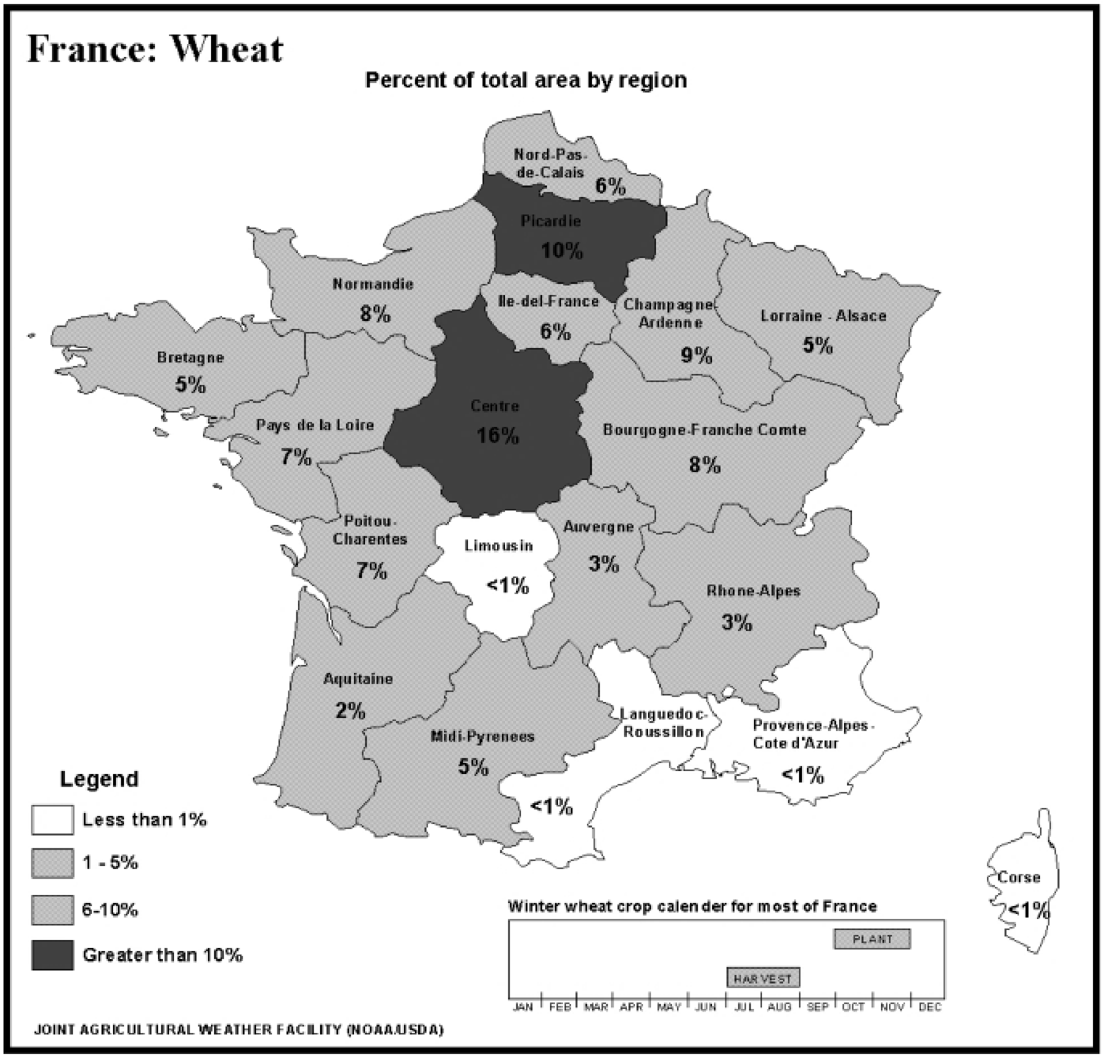


Figure 2.4 France wheat production map

Just as with the United States and other Northern Hemisphere regions, winter wheat is planted from the beginning of October through the end of November in Europe. The harvest season begins around the first of July and is usually finished by the end of August.

2.5.3 Canada

Canada was the third-largest wheat exporting region during the timeframe from 1980 to 2013. Canada produces approximately 25 million tons of wheat annually, with the majority of the production taking place in the three provinces of Saskatchewan, Manitoba, and Alberta. Saskatchewan alone accounts for about 60% of Canada's wheat production, and most of its production is exported to overseas markets (Wheat Initiative, 2014). The planting period is longer in Canada due to its high latitude and colder weather. Winter wheat planting in Canada begins around the first of September through the end of October and harvest begins around the first of July and runs through early September (USDA, 2014).

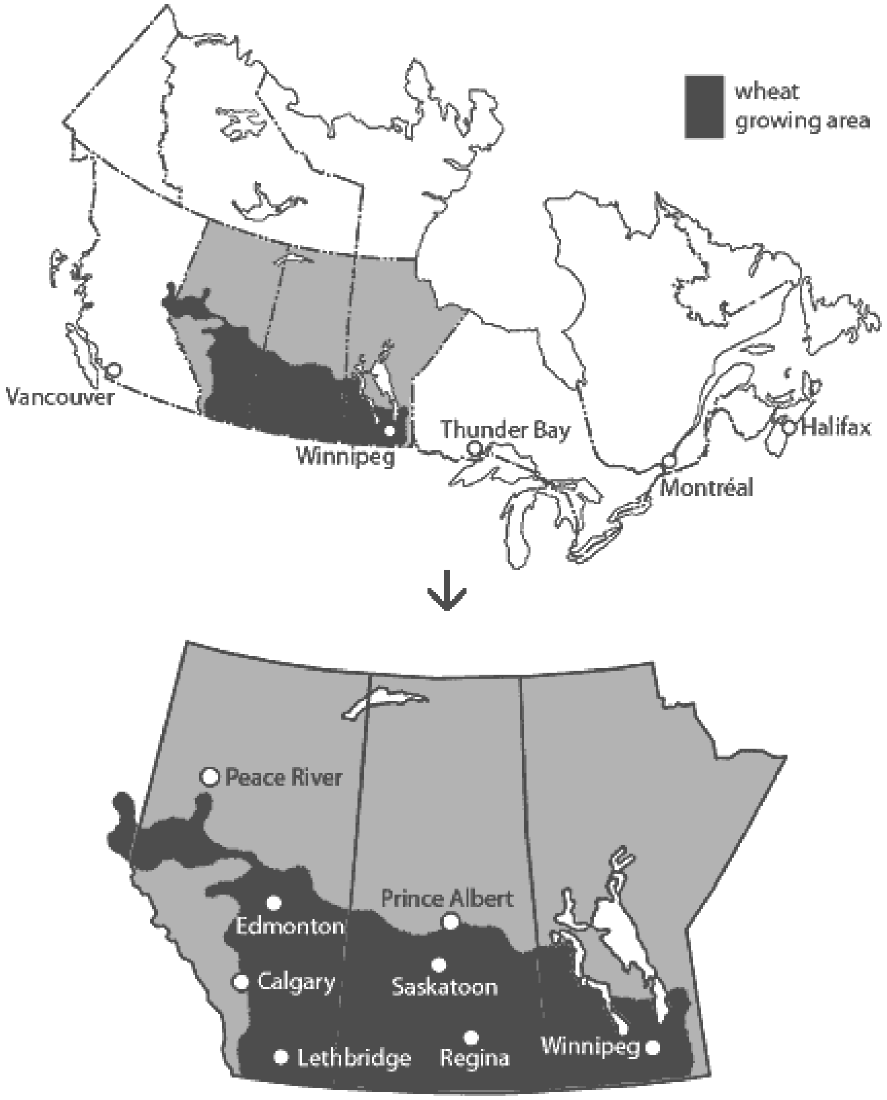


Figure 2.5 Canada wheat production map

2.5.4 Australia

Australia is the next-largest wheat exporter. Total harvested wheat-producing acreage in 2013 was 13.5 million hectares, yielding 27 million metric tons of wheat. In the same year, 18.6 MMT of wheat was exported to the world market from Australia. The main producing state is Western Australia; and subsequently, the majority of Australian wheat is sold overseas from this state's supplies (AGDA, 2015).

Since Australia is located in the Southern hemisphere, it has a different planting calendar.

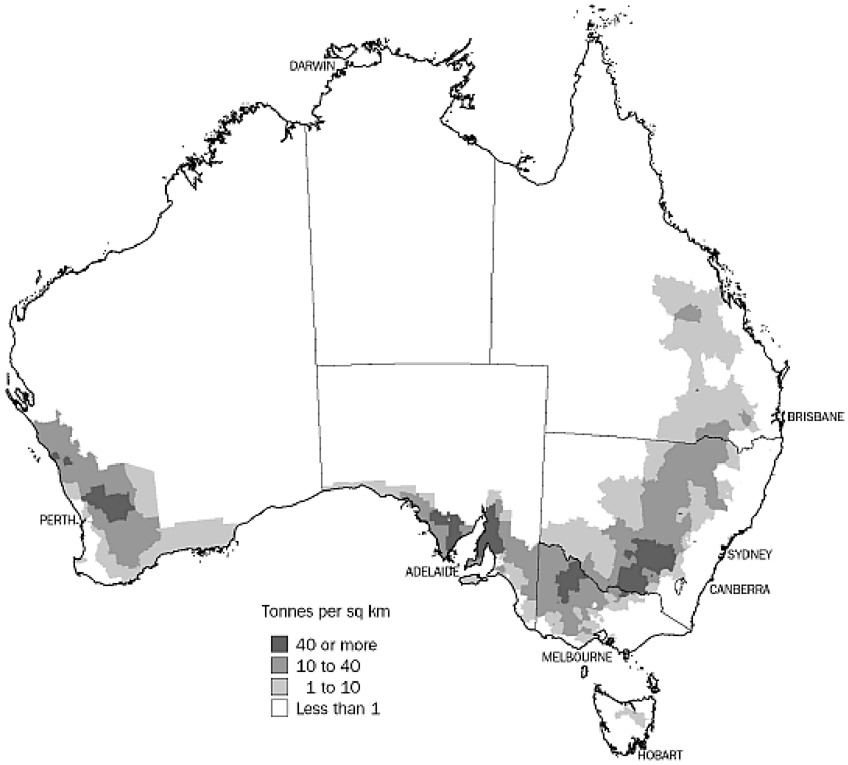


Figure 2.6 Australia wheat production map

In Australia, most wheat is planted during April, May and June, as the seed requires the colder weather to germinate. This allows harvesting before the onset of harsh summer weather conditions. The harvest begins in Queensland during September and October and ends in Western Australia during January (Year Book Australia, 2006).

2.5.5 The Former Soviet Union

The Former Soviet Union (FSU) countries are the fifth-largest wheat exporting region during this 34-year timeframe; their exports have increased consistently from 1991, on average, by 1.58 million tons annually. More than 90 percent of wheat production in the FSU occurs in Russia, Ukraine, Kazakhstan and Uzbekistan (USDA, 2014). Also, these four countries account for 99% of FSU wheat exports (Foreign Agricultural Service USDA, 2014). In 2013, 47.7 million hectares were planted in wheat, with 103.9 million metric tons of yield in the FSU. In the same year, total exports were 37.1 million metric tons (USDA, 2014). The cultivation calendar in the FSU is similar to European countries: winter wheat is planted starting in August and running through early October. Harvest will begin in July and continue through the end of August.

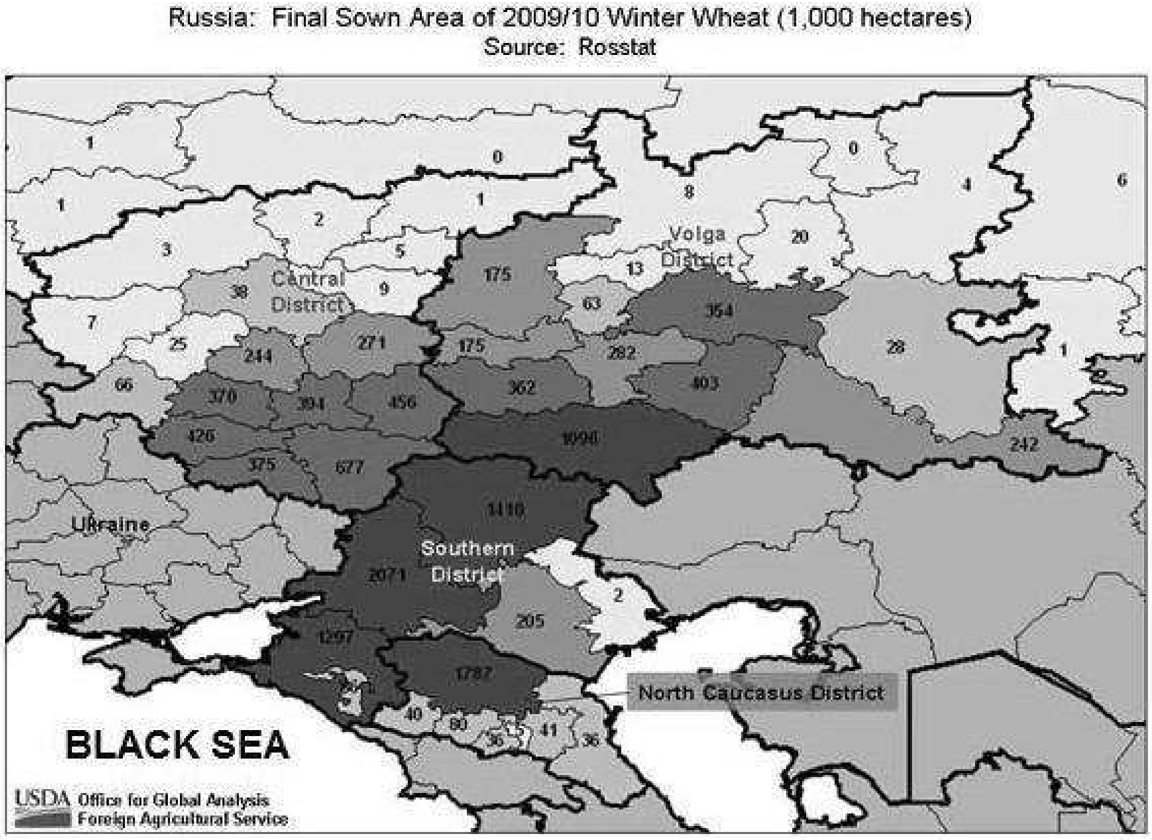

Russia: Final Sown Area of 2009/10 Winter Wheat (1,000 hectares)
Source: Rosstat

Figure 2.7 Former Soviet Union wheat production map

2.6 Demand in Major Wheat-Importing Countries

Demand for wheat has changed over the last several decades, but most of the regions that struggle with drought and low precipitation, including North Africa and the Middle East, South Asia, East and South East Asia, South America, and Sub-Sahara Africa, usually have a high and stable demand for wheat. Based on (FAO) and USDA reports (2014), these five regions are defined as the major wheat importers. They annually import nearly 90% of the total wheat imported in the world (USDA, 2014). Specifically, Egypt was one of the top-five importing countries for the 30 years from 1982 to 2011, with an average of 6 million tons of wheat imports per year (FAO Statistics, 2014). Other countries, such as those in Eastern Europe, had a high demand over a few years between 1980 and 2013 because of war and political or financial problems, but were less consistently among the top importers (FAO statistics, 2014).

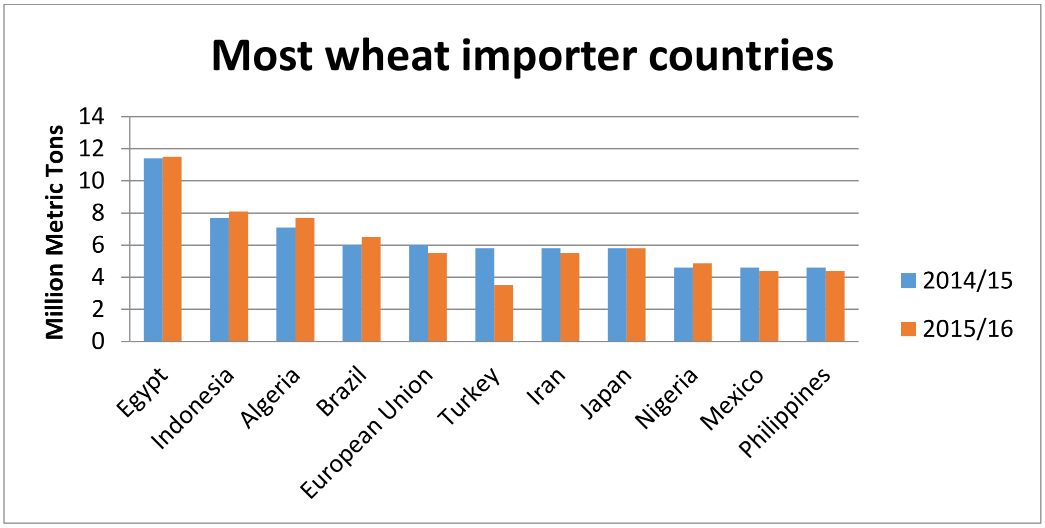


Figure 2.8 Principal importing countries of wheat, flour and wheat products. Data from U.S. Department of Agriculture; USDA Foreign Agricultural Service (June 2015).

3. Data and Methods

The period chosen for this study extends from the agricultural production years of1980 to 2013. Precipitation data is based on National Oceanic and Atmospheric Administration records (NOAA, 2015), and was retrieved for different stations located in the highly-productive regions of each country. The states/regions of Kansas, France, South Saskatchewan, and Southwest of Western Australia represent the United States, The European Union, Canada and Australia, respectively. Krasnodar and Stavropol represent the FSU. The region selected to represent each country has had the highest yield in that country on average during the 34 year timeframe from 1980 to 2013.

For more accurate results, Geographic Information System (GIS) software was used to select specific data related to each region. Weather stations that have been active for all or most of this 34 year time-frame (for at least 25 years) are considered. The map of weather stations for each region are presented in appendix figure A.1.

For the United States, The European Union, Canada and FSU, the average of May and June monthly precipitations is considered for each year. During these months, the wheat plant is in the heading and grain development stage and has the highest water needs (Rogers, 1997). For the same reason, the average of November and December monthly precipitation levels are considered for each year in Australia since it is located in the Southern hemisphere and has a countercyclical agricultural season relative to the other regions.

The precipitation data is reported in millimeters and the average is calculated for the agricultural production year. (Table 3.1)

Table 3.1 Summary of precipitation statistics based on NOAA data

	Kansas State	**France**	**Saskatchewan**	**Western Australia**	**Krasnodar & Stavropol**
Mean	939.34	651.11	640.86	166.50	721.39
Median	916.37	651.27	624.82	144.84	705.27
Maximum	1656.04	1129.09	1022.89	449.12	1082.027
Minimum	419.27	369.25	351.05	52.00	311.67
Std. Dev.	269.44	205.00	163.82	88.96	195.76

Among the five regions, the state of Kansas in the United States has the highest average precipitation levels and the state of Western Australia has the lowest average precipitation during the 34 year time-frame. Annual precipitation in the state of Western Australia, on average, is 166 millimeters compared to other regions that have average annual precipitation of more than 640 millimeters.

To facilitate the interpretation of precipitation data, precipitation of each year is compared to the average precipitation of that region. The long-term average precipitation for every region is calculated over the 34 year time-frame from 1980 to 2013, and subtracted from the raw precipitation data of that region. Therefore the data has been converted to plus/minus the average index (Table 3.2 and Figure 3.1).

Table 3.2 Summary of precipitation statistics in plus/minus average format

	U.S.	Europe Union	Canada	Australia	FSU
Mean	0.0	0.0	0.0	0.0	0.0
Median	-23	0.2	-16	-22	-16
Maximum	717	478	382	283	361
Minimum	-520	-282	-290	-115	-410
Std. Dev.	269.44	205.00	163.82	88.96	195.76

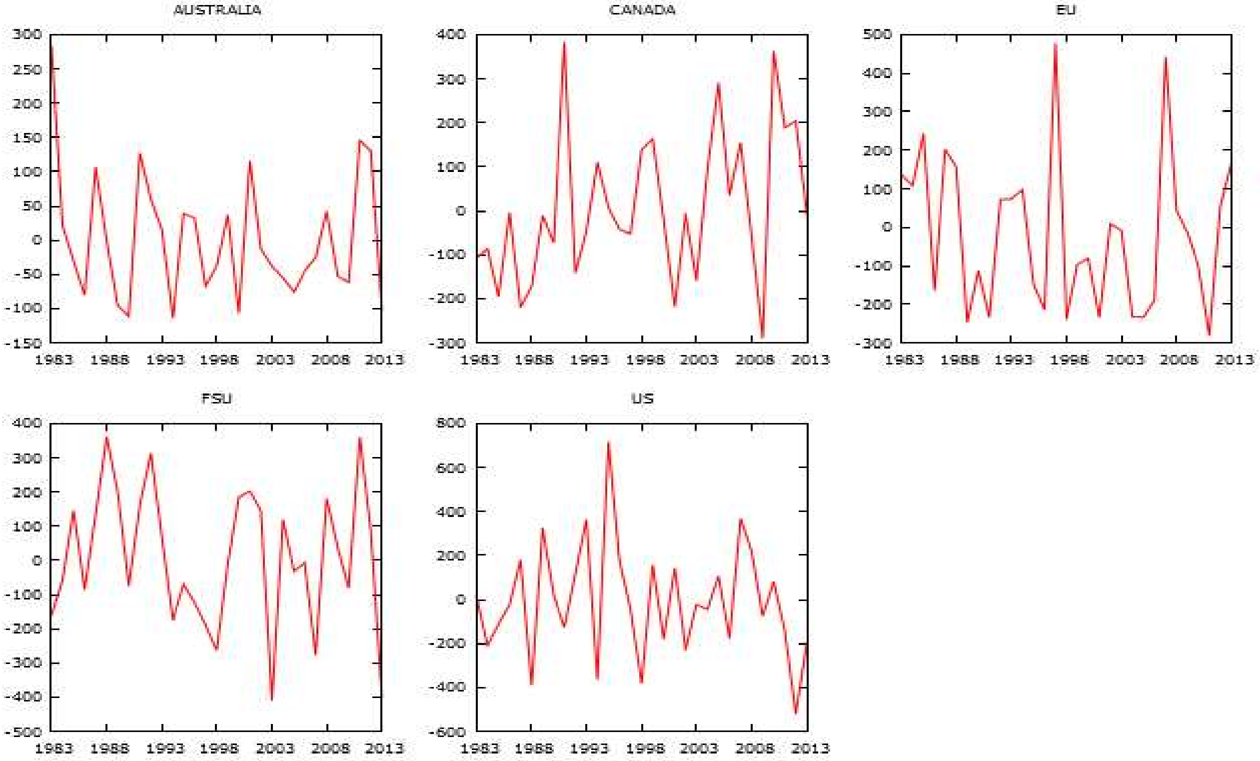


Figure 3.1 Annual precipitation data for each of the regions during the 34 year time-frame, in plus/minus average format

Annual observations for prices, yields, and import data are integrated into the model. Yield data is in metric tons per hectare and was retrieved from OECD-FAO 2015 Agricultural Outlook and USDA Statistical Bulletin (Shend, 1993). After 1992, the sum of Russia, Ukraine, Kazakhstan and Uzbekistan production and exports is used to represent the Former Soviet Union (FSU). The yield was, on average, the highest in the Europe Union; about two times more than the yield in other regions while Australia had the lowest yield during the 34 year time-frame. (Table 3.3 and Figure 3.2)

Table 3.3 Summary of yield data statistics (tons per hectare)
Source: OECD-FAO data

Yield

	U.S.	**Canada**	**Europe Union**	**Australia**	**FSU**
Mean	2.66	2.27	4.77	1.61	1.73
Median	2.65	2.25	4.82	1.63	1.65
Maximum	3.17	3.18	5.68	2.15	2.39
Minimum	2.20	1.23	3.63	0.76	1.27
Std. Dev.	0.28	0.43	0.51	0.38	0.30
Observations	34	34	34	34	34

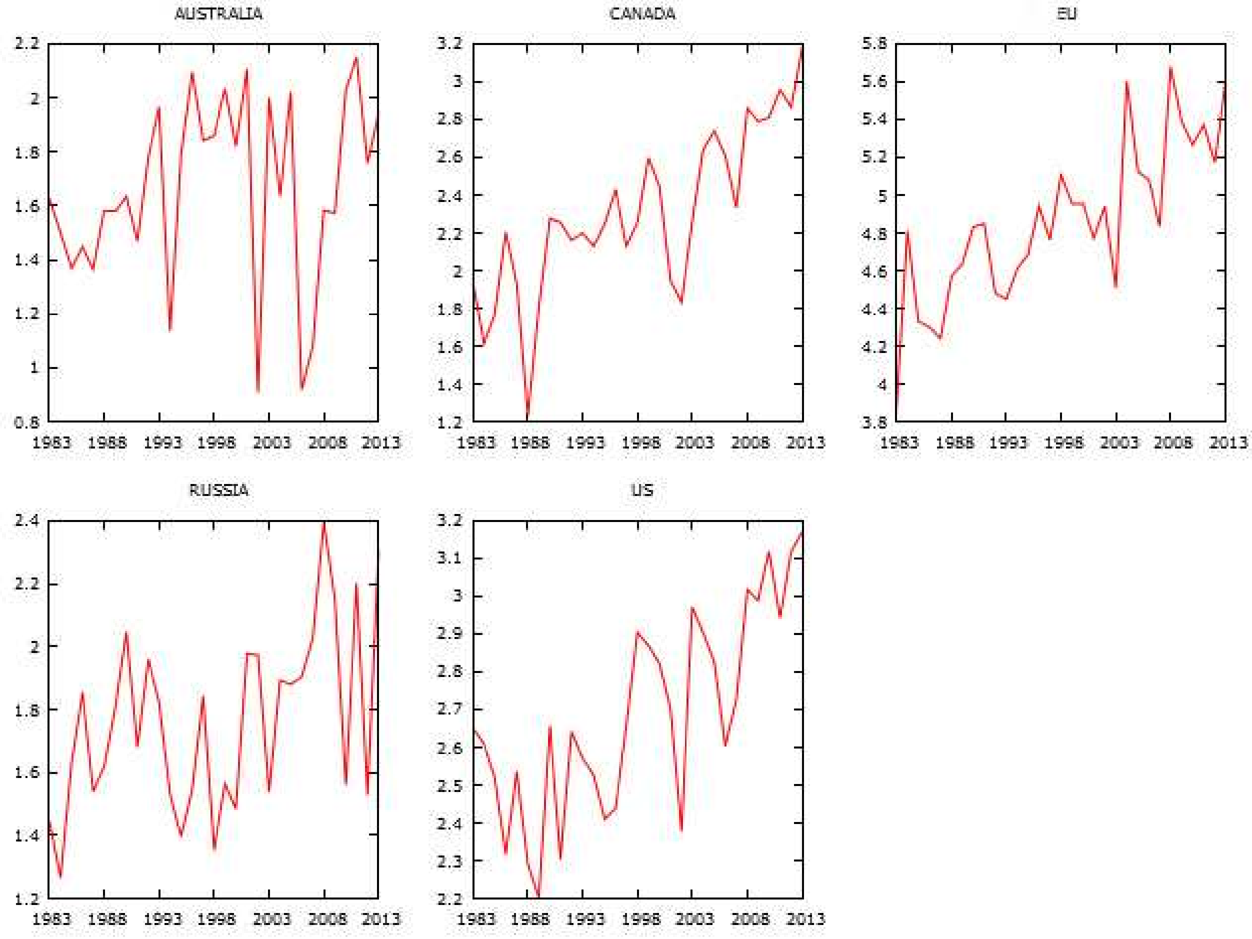


Figure 3.2 Average annual yield data of the regions during the 34 year time-frame
Source: OECD & FAO data

Import data is presented in million metric tons and is collected from FAO statistics for the 34 year time-frame. This scale, presented in 10^6 Ton, has also been used in the regression analysis. During this time-frame, the maximum annual import level is 162 million tons in 2013, and the minimum is 88.06 million tons in 1986. The average world import level during the time-frame is 113 million tons and the trends exhibited in annual world import data is shown in Figure 3.3.

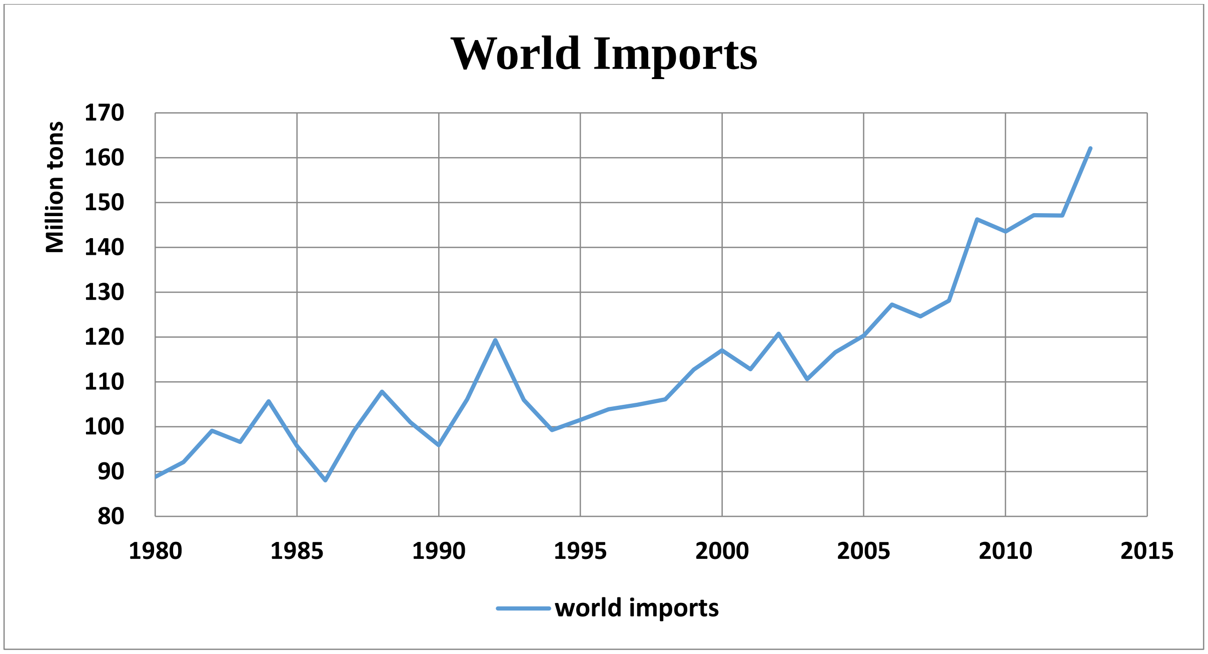


Figure 3.3 Annual world wheat imports
Source: FAO

Summary of the data for wheat world prices is presented in Table 3.4. The lowest deflated price for wheat was $151.70/ton in 1998, for which the nominal price is $107.96/ton. The highest deflated price of wheat was $409.41/ton in 1980, with a nominal price of $148/ton. Figure 3.4 shows the trend for annual wheat prices during the 34 year time-frame.

Table 3.4 Summary of data statistics for annual wheat price in U.S. dollars per ton and deflated to 2013 dollars
Source: FAO s

	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
Price($)	252.62	236.67	409.41	151.70	67.39	34

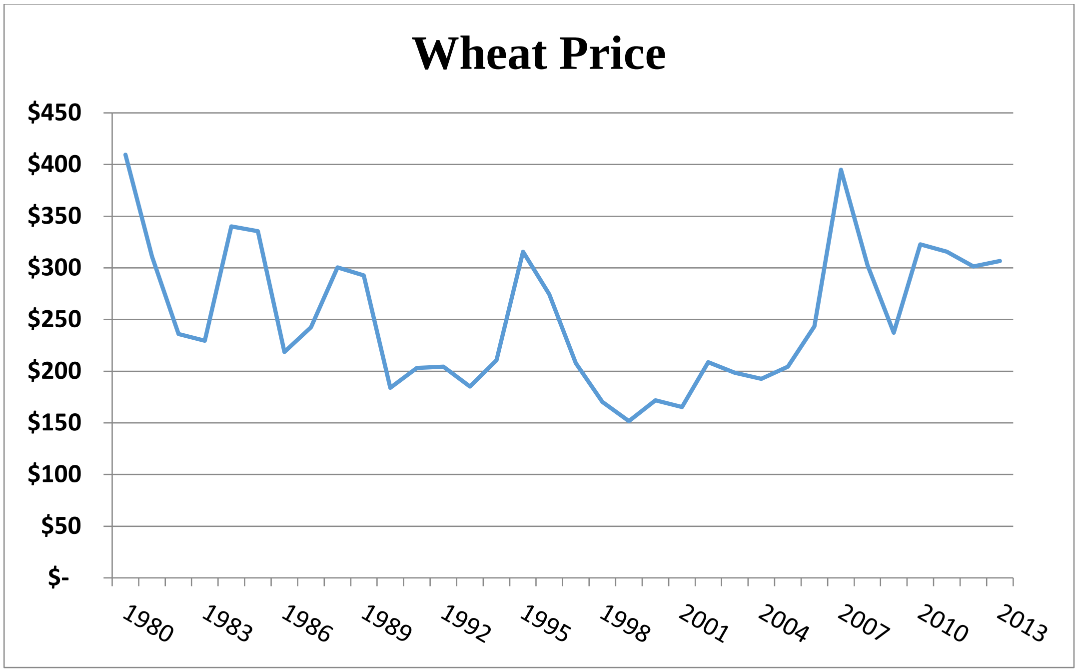


**Figure 3.4 Annual world wheat price, deflated to 2013 dollars,
Source: FAO**

Annual oil price is calculated as the average of two oil prices; West Texas Intermediate oil and the Persian Gulf countries' crude oil. Oil prices are reported in US Dollars per barrel and data is collected from the U.S. Energy Information Administration. All prices were adjusted to 2013 dollars (Table 3.5).

Table 3.5 Average annual oil price statistics in U.S. dollars per barrel, deflated to 2013 dollars

	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
Oil Price	$ 49.21	$ 34.60	$ 104.64	$ 14.33	$ 27.60	34

The lowest oil price over this period was $14.33/barrel for 1998, which is also the year with the lowest wheat price. The peaks in oil prices are relatively recent; those occurred in 2008, 2011 and 2012 when the oil price was above $100/barrel when deflated to 2013 dollars (Figure 3.5).

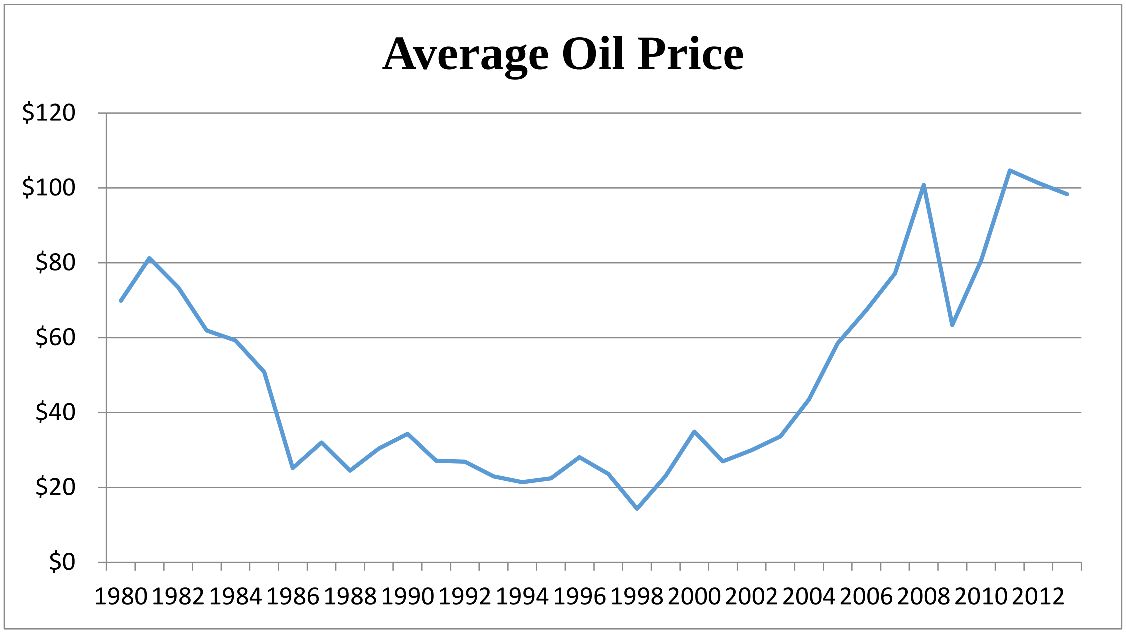


Figure 3.5 Average annual Oil price in U.S. dollars per barrel, deflated to 2013 dollars Source: EIA

The Ordinary Least Square (OLS) method, packaged in Eviews is used to investigate correlations between world wheat prices and the quantity of world wheat imports, the average oil price, precipitation index and yield in the five major wheat producing countries, and the wheat price of the previous year. For this model, the inverse form was selected to consider price as the dependent variable explained by other supply factors. The basic assumption is that demand is more steady than supply.

The estimation is based on the following Equation 3.1:

$$\mathrm{P_t} = \beta_0 + \beta_1 \mathrm{I_t} + \beta_2 \mathrm{P_{t-1}} + \beta_3 \mathrm{R_{t-US}} + \beta_4 \mathrm{R_{t-EU}} + \beta_5 \mathrm{R_{t-CA}} + \beta_6 \mathrm{R_{t-AU}} + \beta_7 \mathrm{R_{t-FSU}} + \beta_8 \mathrm{Y_{t-US}} + \beta_9 \mathrm{Y_{t-EU}} + \beta_{10} \mathrm{Y_{t-CA}} + \beta_{11} \mathrm{Y_{t-AU}} + \beta_{12} \mathrm{Y_{t-FSU}} + \beta_{14} \mathrm{O_t} + \varepsilon_\mathrm{t} \qquad \text{(Equation 3.1)}$$

where P_t is the world wheat price, I_t is the total world wheat imports, P_{t-1} is the previous year's world wheat price, R_{t-US} is the precipitation index in the U.S., R_{t-EU} is the precipitation index in the European Union, R_{t-CA} is the precipitation index in Canada, R_{t-AU} is the precipitation index in Australia, R_{t-FSU} is the precipitation index in the Former Soviet Union, Y_{t-US} is the yield in the U.S., Y_{t-EU} is the yield in the European Union, Y_{t-CA} is the yield in Canada, Y_{t-AU} is the yield in Australia, $Y_{t-\mathrm{FSU}}$ is the yield in the Former Soviet Union, and O_t is the average oil price.

All prices are deflated based on the 2013 consumer price index (CPI) reported by the U.S. Bureau of Labor Statistics (2015). To deflate prices, we standardized by CPI using the following equation:

$$\mathrm{C_t} = \frac{\mathrm{CPI_{2013}}}{\mathrm{CPI_t}} \times 100 \quad (3.2)$$

Where $\mathrm{C_t}$ is the CPI index for each particular year based on 2013 dollars. $\mathrm{CPI_t}$ is the CPI index for that year and is raw data from Bureau of Labor Statistics. $\mathrm{CPI_{2013}}$ is the price index for 2013 based on BLS statistics and is equal to 229.324.

For example, it is expected that the oil price has a simple direct effect on wheat price; where an increase in the oil price results in a subsequent increase in wheat prices. The hypothesis and the null hypothesis are:

$$H_0: \beta_{14} = 0$$

$$H_1: \beta_{14} \neq 0$$

where β is the linear correlation coefficient for oil price during the study time-frame. The same applies to the investigation of the effect of other factors on wheat price.

A Chow test was performed to investigate structural stability of data. This method uses an F-test to find if there has been any structural change in data during the time-frame of analysis. In other words, it investigates if splitting the data into two sub-samples and using two separate regressions is more effective than a single regression including all the data across the full time period. Break points in data across time can result from economic shocks or changes in policies.

Since in this study several countries are considered over several decades, it is particularly important to perform this test to assure there was not a regime shift in different time periods for any of the included trading countries. For example, in 1992 the FSU collapsed, and sudden political and economic changes followed that made this year a potential point for a structural data break. The test statistic used for this test can be represented as:

$$\mathrm{F} = \frac{[\mathrm{SSE_P} - (\mathrm{SSE_1} + \mathrm{SSE_2})]/\mathrm{k}}{(\mathrm{SSE_1} + \mathrm{SSE_2})/(\mathrm{N_1} + \mathrm{N_2} - 2\mathrm{k})}$$

where $\mathrm{SSE_P}$ is the sum of the squared error terms for the pooled model, and $\mathrm{SSE_1}$ and $\mathrm{SSE_2}$ are the sum of the squared error terms for first and second groups, respectively. The variable k represents the number of estimated parameters and N's are the number of each group. Comparison of the results of the F test with the F test critical values shows that a structural break likely occurred in that particular year. A higher F value at the chosen level of significance shows a break point in the specific year and instability of the parameters. Otherwise, the null hypothesis is rejected, error terms are normally distributed and data consistency is verified.

Autocorrelation in time series data is another factor that may cause unintentional bias or misinterpretation of results. In this study, the Durbin-Watson test was performed to detect autocorrelation. This test detects if the data is auto-correlated by checking if the residuals of the regression analysis are correlated. The test statistic is:

$$\mathrm{d} = \frac{\sum_{\mathrm{i}=2}^{\mathrm{n}}(\mathrm{e_i} - \mathrm{e_{i-1}})^2}{\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{e_i^2}}$$

where $\mathrm{e_i} = \mathrm{y_i} - \hat{\mathrm{y}}_\mathrm{i}$ and $\mathrm{y_i}$ and $\hat{\mathrm{y}}_\mathrm{i}$ the observed and predicted values of the response variable for individual i, respectively. The null hypothesis in Durban-Watson test assumes no autocorrelation exists between the independent variables, so if the test result shows higher or lower than the critical

d value at the chosen level of significance, the null hypothesis is rejected and autocorrelation is verified. Autocorrelation indicates non-randomness in data series, so if it is present, data can be transformed to address the issue.

Regression analysis was performed on the entire data that spans from 1980 to 2013, initially. The results showed significant residual errors for the first three years, from 1980 to 1982, the year when the residuals from the regression was largest. Therefore, a second regression was performed on the data from just the period of 1983 to 2013, and structural stability and autocorrelation of this data were then tested to see if improved results could be obtained.

4. Results

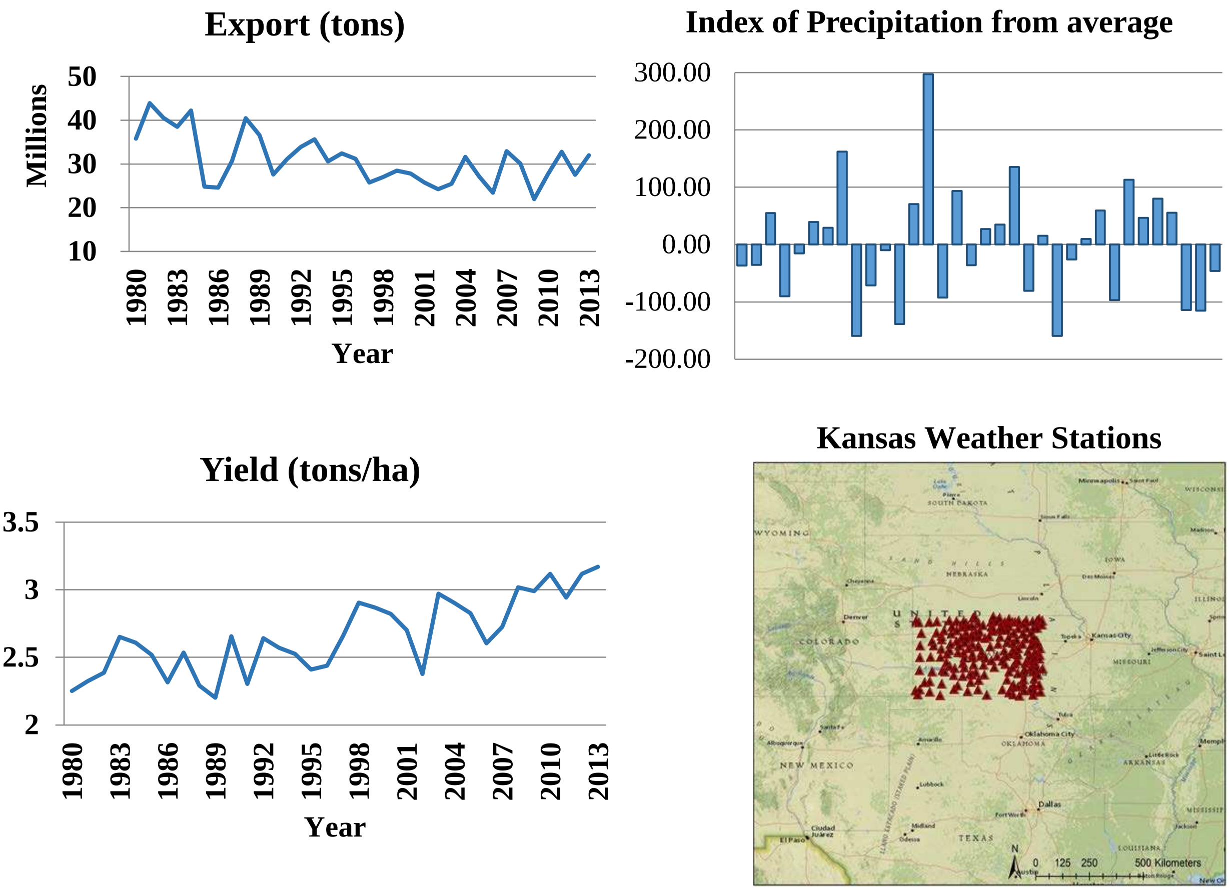
This section summarizes the results of the data analyses, including the regression analysis and statistical tests. Ordinary Least Square (OLS) regression analysis, together with diagnostic Chow and Durbin-Watson autocorrelation tests were carried out to explore the relationships between world wheat prices, world wheat imports, average annual oil prices, the precipitation index and yields in the five major wheat producing regions, as well as the world wheat price from the previous year. Discussion of the findings can be used to draw inferences and form some implications for the market from this work.

As expected, since the precipitation index is driven by each region's historical precipitation pattern and these vary over the 34-year period, we will likely see varying price dynamics as well. As a reminder from data explored in the previous section, all wheat exporting regions have an average annual precipitation of more than 600 millimeters, except for Australia, with 166.5 millimeters, which was found to be statistically significantly different from the other regions. Figure 3.1 illustrates the precipitation trends.

4.1. Outlook on Major Wheat-Exporting Countries

Presentation of the information for each country/region in charts better demonstrates wheat production trends over time in five major export regions. The following section shows more details on each key wheat-exporting country to complement the discussion of findings on price behavior.

4.1.1 United States (Kansas)


Export (tons)

Index of Precipitation from average

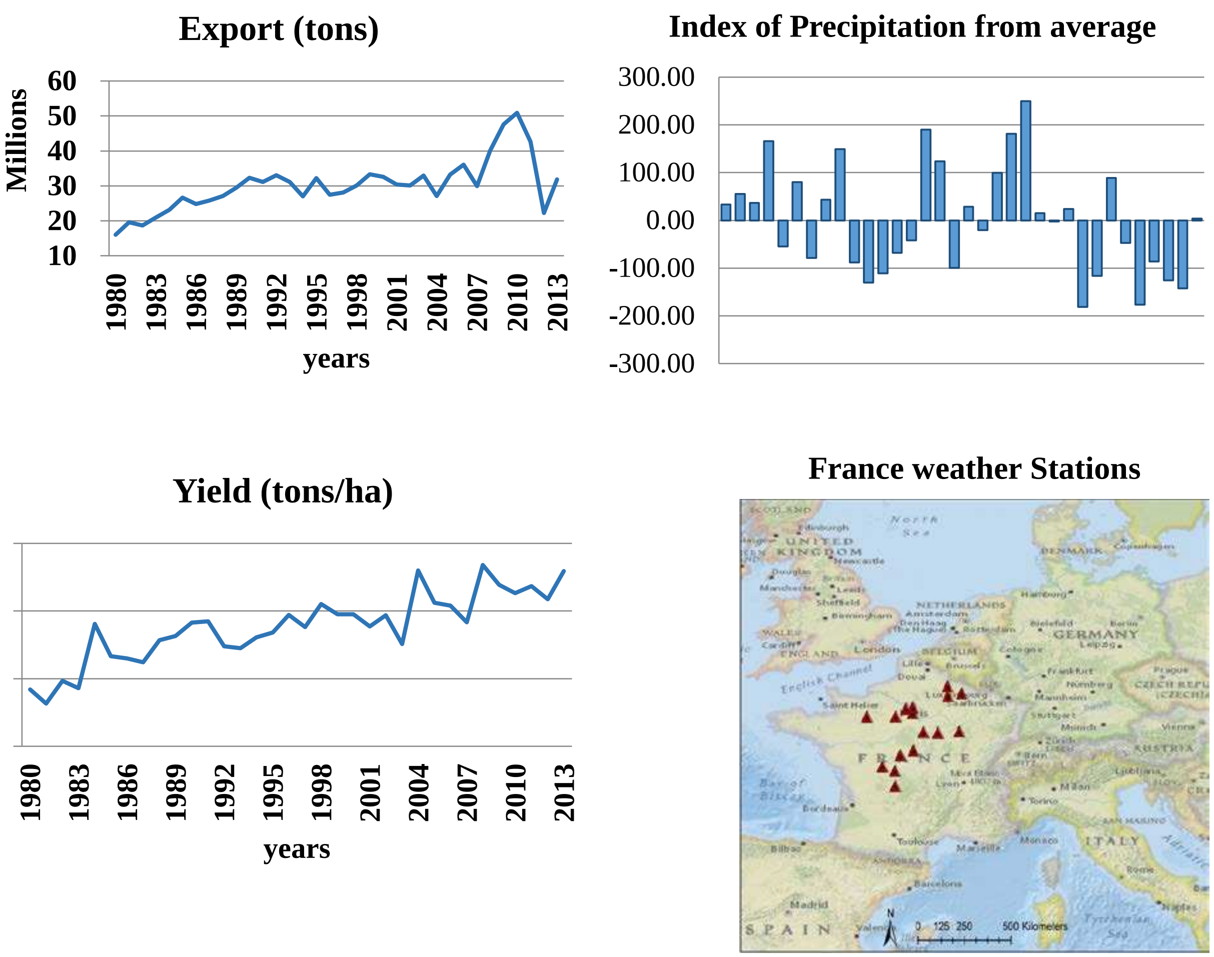
Yield (tons/ha)

Kansas Weather Stations

Figure 4.1 United States Precipitation, Yield, export, and weather stations map outlook during 1980 to 2013. Precipitation is shown in +/- from average index (see page 28) Source: OECD-FAO, NOAA, and FAOSTAT.

United States wheat exports decreased over the 34 year timeframe, yield increased gradually from two tons per hectare to more than three tons per hectare, and precipitation varies from the average in no discernable pattern without any long wet or dry periods. The weather stations from which precipitation data is collected are shown on the map (Figure 4.1).

4.1.2 European Union (France)


Export (tons)

Index of Precipitation from average

Yield (tons/ha)

France weather Stations

Figure 4.2 European Union Precipitation, Yield, export, and weather stations map outlook during 1980 to 2013. Precipitation is shown in +/- from average index (see page 28) Source: OECD-FAO, NOAA, and FAOSTAT.

The European Union’s wheat exports increased over time, as did wheat yields. This region has the highest yield in the world with current yields totaling more than five tons per hectare. Compared to other regions, precipitation patterns in the E.U. exhibit periodic dry and wet years during the time-frame of this study. The weather stations from which precipitation data is collected are shown on the map (Figure 4.2).

4.1.3 Canada (Saskatchewan)

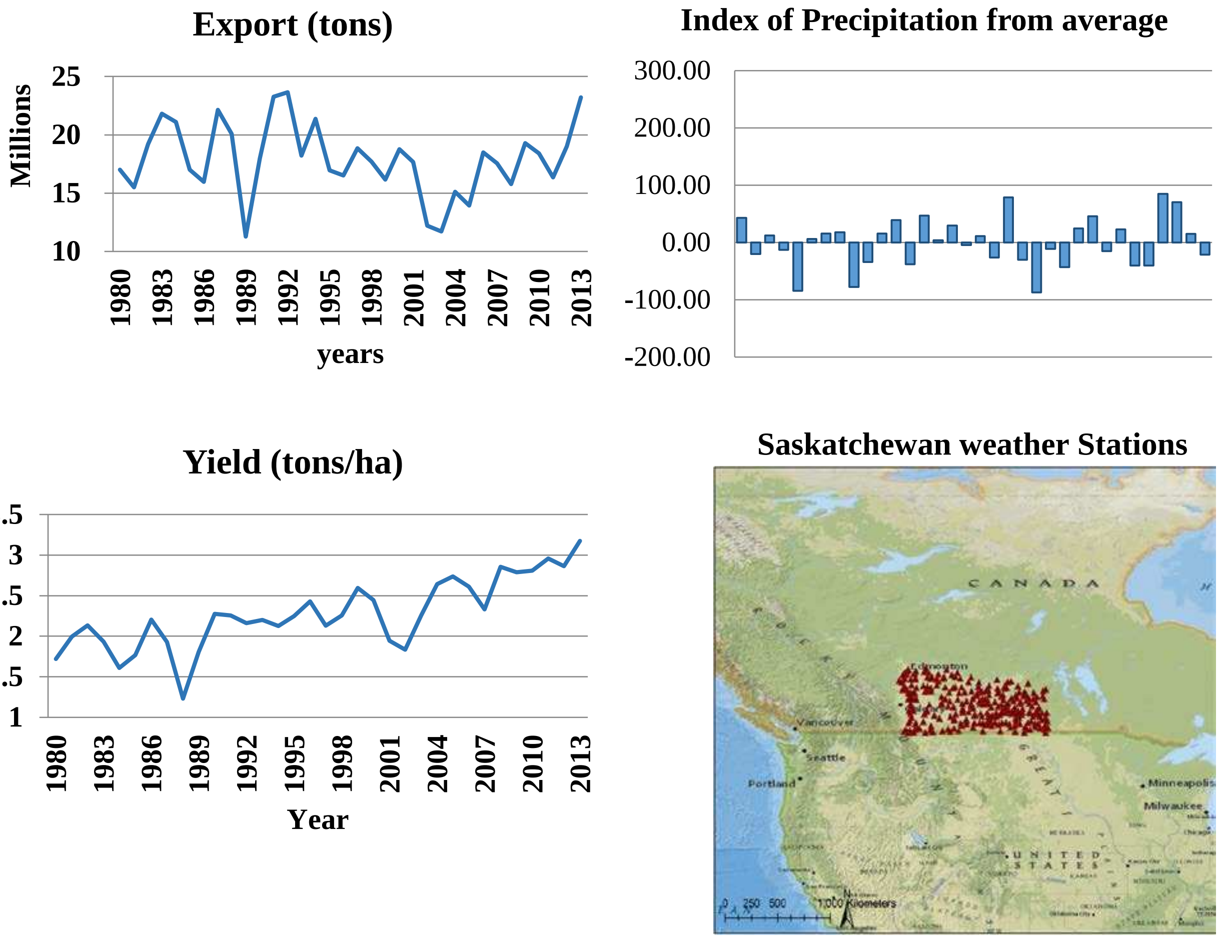


Figure 4.3 Canada Precipitation, Yield, export, and weather stations map outlook during 1980 to 2013. Precipitation is shown in +/- from average index (see page 28)
Source: OECD-FAO, NOAA, and FAOSTAT.

The changes in exports from Canada varied during the time frame considered. Unlike the patterns in exports, precipitation levels were less variable. Like the U.S., yields have increased slowly over time in Canada, from one ton per hectare to three tons per hectare. The weather stations from which precipitation data is collected are shown on the map (Figure 4.3).

4.1.4 Former Soviet Union (Southern)

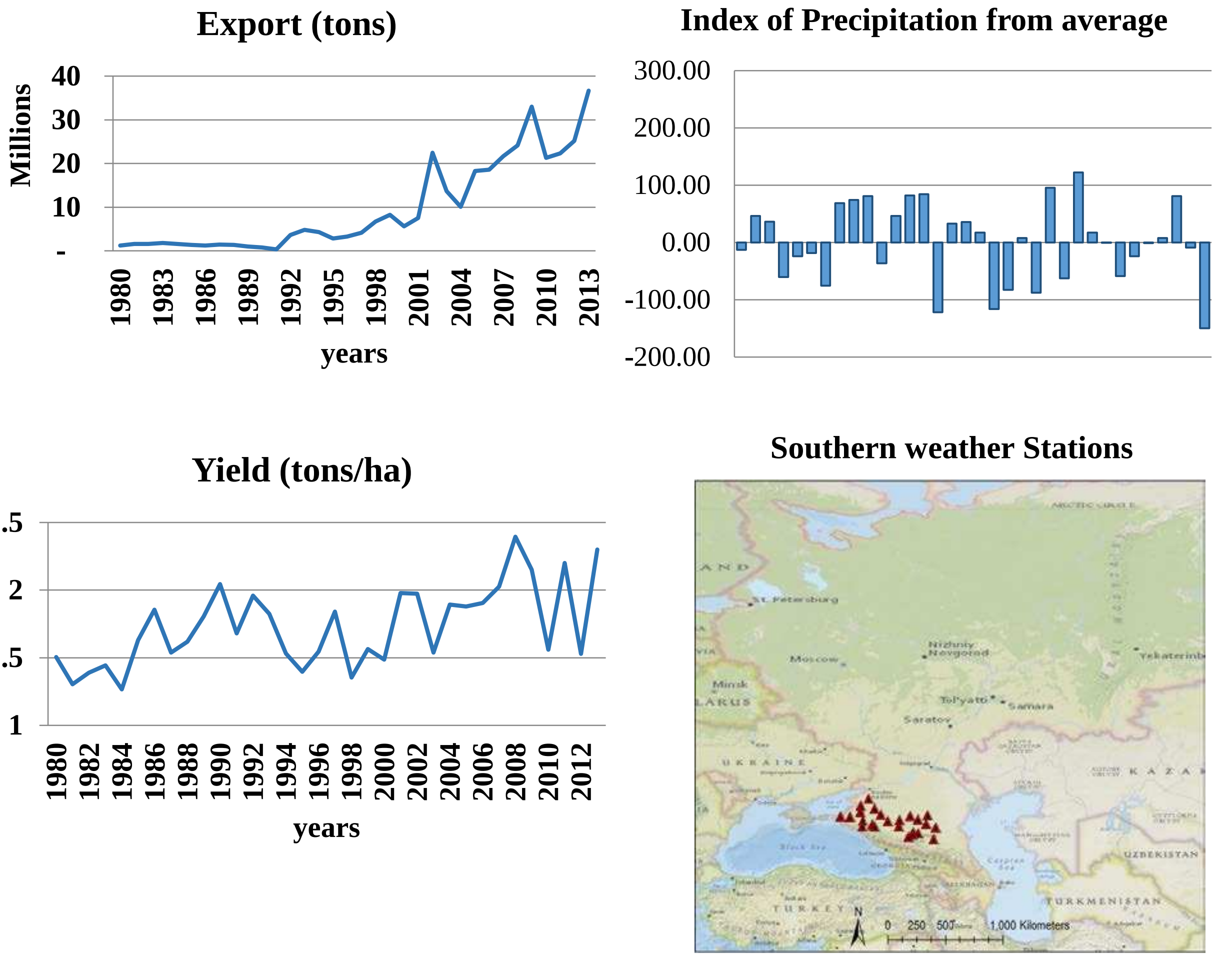


Figure 4.4 Former Soviet Union Precipitation, Yield, export, and weather stations map outlook during 1980 to 2013. Precipitation is shown in +/- from average index (see page 28) Source: OECD-FAO, NOAA, and FAOSTAT.

Almost no exports were reported for the region before the dissolution of the Soviet Union. After 1992, the region’s exports grew to nearly 40 million tons, most of which happened after the year 2000. Also, average yields increased over time from less than 1.5 to 2 tons per hectare. The highest levels of wheat production in FSU are in Southern Russia. Precipitation has been relatively constant over the time period considered. The weather stations from which precipitation data is collected are shown on the map (Figure 4.4).

4.1.5 Australia (Western Australia)

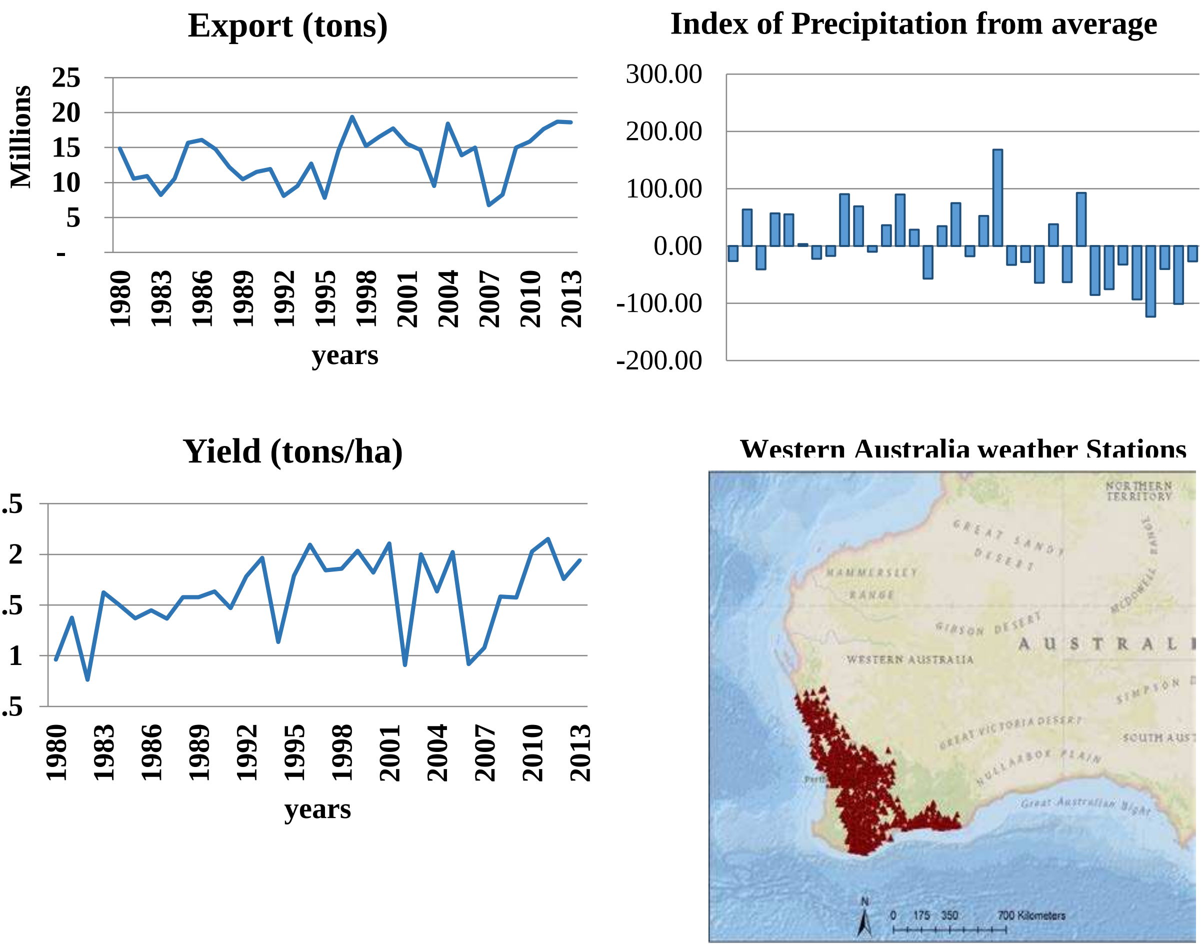


Figure 4.5 Australia Precipitation, Yield, export, and weather stations map outlook during 1980 to 2013. Precipitation is shown in +/- from average index (see page 28)
Source: OECD-FAO, NOAA, and FAOSTAT.

Australia’s exports and yield have both increased gradually over time. With an average annual precipitation of 166.5 mm, Australia has the lowest precipitation levels compared to other regions. Precipitation levels in recent years indicate a long period of drought in the Western Australia region. The weather stations from which precipitation data is collected are shown on the map (Figure 4.5).

4.2. Analysis

The OLS analysis of the data was conducted using Eviews software, the specification is shared below and the results are summarized in Table 4.1.

$$\mathrm{P_t} = \beta_0 + \beta_1 \mathrm{I_t} + \beta_2 \mathrm{P_{t-1}} + \beta_3 \mathrm{R_{t-US}} + \beta_4 \mathrm{R_{t-EU}} + \beta_5 \mathrm{R_{t-CA}} + \beta_6 \mathrm{R_{t-AU}} + \beta_7 \mathrm{R_{t-RU}} + \beta_8 \mathrm{Y_{t-US}} + \beta_9 \mathrm{Y_{t-EU}} + \beta_{10} \mathrm{Y_{t-CA}} + \beta_{11} \mathrm{Y_{t-AU}} + \beta_{12} \mathrm{Y_{t-RU}} + \beta_{14} \mathrm{O_t} + \varepsilon_t$$

where P_t is the world wheat price, I_t is the total world wheat imports, P_{t-1} is the previous year's world wheat price, R_{t-US} is the precipitation index in the U.S., R_{t-EU} is the precipitation index in the European Union, R_{t-CA} is the precipitation index in Canada, R_{t-AU} is the precipitation index in Australia, R_{t-FSU} is the precipitation index in the Former Soviet Union, Y_{t-US} is the yield in the U.S., Y_{t-EU} is the yield in the European Union, Y_{t-CA} is the yield in Canada, Y_{t-AU} is the yield in Australia, $Y_{t-\mathrm{FSU}}$ is the yield in the Former Soviet Union, and O_t is the average oil price.

$$\widehat{\mathrm{P}}_\mathrm{t} = 104.63 + 0.00\ \mathrm{I_t} + 0.515 \mathrm{P_{t-1}} + 0.070 \mathrm{R_{t-US}} + 0.032 \mathrm{R_{t-EU}} + 0.063 \mathrm{R_{t-CA}} + 0.013 \mathrm{R_{t-AU}} - 0.049 \mathrm{R_{t-FSU}} - 60.04 \mathrm{Y_{t-US}} + 59.68 \mathrm{Y_{t-EU}} - 129.66 \mathrm{Y_{t-CA}} + 31.21 \mathrm{Y_{t-AU}} - 59.45 \mathrm{Y_{t-RU}} + 0.925 \mathrm{O_t}$$

Table 4.1 Regression results, 1980 to 2013

	Variable	Symbol	Coefficient	Standard Error	t-Statistic	P-value	
	Imports	I_t	2.1873	1.0314	2.1206	0.0466	*
	Oil Price	O_t	0.9250	0.7030	1.3158	0.2031	
Precipitation index	Australia	R_{t-AU}	0.0131	0.0963	0.1366	0.8927	
	Canada	R_{t-CA}	0.0835	0.0632	1.3208	0.2015	
	Europe Union	R_{t-EU}	0.0322	0.0486	0.6630	0.5149	
	Former Soviet Union	R_{t-FSU}	-0.0492	0.0467	-1.0552	0.3039	
	United States	R_{t-US}	0.0703	0.0333	2.1094	0.0477	*
Yield	Australia	Y_{t-AU}	-3.5343	31.2137	-0.1132	0.9110	
	Canada	Y_{t-CA}	-129.6632	42.5186	-3.0496	0.0063	**
	Europe Union	Y_{t-EU}	59.6849	31.6355	1.8866	0.0738	
	Former Soviet Union	Y_{t-FSU}	-59.4554	34.9626	-1.7005	0.1045	
	United States	Y_{t-US}	-60.0434	73.2320	-0.8199	0.4219	
	Previous Year Price	P_{t-1}	0.5147	0.1856	2.7730	0.0117	*
	Constant	C	104.6386	136.4058	0.7671	0.4520	

For the regression that covers the entire 34-year timeframe, the R squared value is 0.8072, indicating that the variables explain about 81 percent of variation in world wheat price. The standard error is 38.013 and the F-statistic is 6.4413, indicating significance at one percent level (Table 4.2).

Table 4.2 Regression statistics for data from 1980 to 2013

R-Squared	0.8072	F-Statistic	6.4413
Adjusted R-Squared	0.6819	Probability (F-Statistic)	0.0001
Standard Error of Regressior	38.013	Sum of the Squared Residual	28900.2

The significant variables for the model are indicated by asterisks (*) in Table 4.1. Variables with one asterisk are significant at the 5% level of significance and those with two asterisks are significant at the 1% level.

The analysis indicates a linear correlation between wheat imports and prices at a 5% level of significance. A one unit increase in imports (measured in million tons), is associated with a 2.19

unit increase in the world wheat price (measured in U.S. dollars) if other variables are assumed constant. In all major exporting regions, except for the United States, precipitation does not have a significant relationship with the wheat price in the same year the precipitation level was recorded. In the United States, the effects of precipitation on the world price are statistically significant. In this case, a one unit increase in precipitation (mm) in the United States is associated with a 0.07 dollar increase in the wheat price at the five percent level of significance. This change in wheat price caused by a one unit change in precipitation in Australia, Canada, E.U., and FSU, are 0.013, 0.084, 0.032, and -0.049 dollars, respectively, if all other variables are assumed constant. But these values are not statistically significant in the model as indicated by the respective P-value of each estimate.

Yields reported from the exporting regions do not have a significant relationship with wheat price in the model, except for the wheat yield in Canada which is statistically significant. In Canada, the estimated coefficient for precipitation is not significant, whereas yield is estimated to have a statistically significant effect on wheat prices. In order to be more comprehensive, future work should include additional factors such as broader climate change variables including average temperature, seasonal thaw and freeze dates.

In Canada, a one unit (tons per hectare) increase in yield is associated with a 129.66 unit (U.S. dollars per ton) decrease in world wheat price, which is a statistically significant estimate at the one percent level, showing a strong relationship between Canadian wheat yield and world price levels over the timeframe. In contrast, the change in wheat price for Australia, E.U., and FSU, and U.S., are -3.53, 59.68, -59.46, and -60.04 dollars per ton respectively, if all other variables are assumed constant, but these values are not statistically significant.

The R-squared value of 0.8072 suggests that the regression model explains approximately 80% of the world wheat price level. However, the sum of the squared residual is equal to 28900, which is relatively high as this residual indicates the difference between the predicted values and the actual observed values. This indicated that more diagnostic testing on the model may be needed.

The Chow test was conducted for this model and results show no structural break at the specified breakpoint of 1992. The Chow test's null hypothesis assumes the existence of break point in a specific year, and divides the analysis into two linear regressions, testing for the equality between coefficients and error terms in the two linear regressions. The F-statistic of the Chow test is equal 2.424 with probability equal to 0.1413 (Appendix 5.1). This means that the null hypothesis was rejected with a five percent significance level, so the error terms are normally distributed. Also the Durbin-Watson d test shows the value of 1.575 between d_l and d_u values (Appendix 2.2). So with one and five percent significance levels there is no conclusive evidence regarding the presence or absence of positive first order autocorrelation.

To improve the regression results, the residual for each year was obtained from the Eviews software and relationships among errors were further investigated. The residuals for the first three years of the time-frame were found to be significantly larger than the reminder of the timeframe and therefore a second regression was conducted on the data from just the timeframe including 1983 to 2013. (Appendix Figure A.3.2) Historically, there were oil price shocks and a surge in wheat exports that gave rise to unusual wheat price spikes in the early 1980's. But the wheat price dropped later as production in developing countries increased and the growth rate of wheat consumption decreased (Mitchell, 2005), so censoring these atypical years may improve the model's fit. Accordingly, table 4.3 shows the regression results for the same model described above, using the subset of the data representing 1983 to 2013.

Table 4.3 – Regression results for data from 1983 to 2013

	Variable	Symbol	Coefficient	Standard Error	t-Statistic	P-value	
	Imports	I_t	2.0615	0.6389	3.2268	0.0050	**
	Oil Price	O_t	1.6620	0.4484	3.7068	0.0018	**
Precipitation index	Australia	R_{t-AU}	-0.0910	0.0619	-1.4686	0.1602	
	Canada	R_{t-CA}	0.0491	0.0396	1.2384	0.2324	
	Europe Union	R_{t-EU}	0.0448	0.0322	1.3948	0.1810	
	Former Soviet Union	R_{t-FSU}	-0.0279	0.0287	-0.9705	0.3454	
	United States	R_{t-US}	0.1032	0.0214	4.8311	0.0002	**
Yield	Australia	Y_{t-AU}	-10.7002	20.9678	-0.5103	0.6164	
	Canada	Y_{t-CA}	-92.0341	26.7847	-3.4361	0.0032	**
	Europe Union	Y_{t-EU}	32.3921	21.5762	1.5013	0.1516	
	Former Soviet Union	Y_{t-FSU}	-105.3465	22.8909	-4.6021	0.0003	**
	United States	Y_{t-US}	-98.2063	46.2547	-2.1232	0.0487	*
	Previous Year Price	P_{t-1}	0.4269	0.1272	3.3549	0.0038	**
	Constant	C	350.8072	95.2140	3.6844	0.0018	**

For the regression including the more recent 31 years, the fit of the model improved with a regression R squared of 0.9239, standard error of 23.213, and F-statistic of 15.87 (Table 4.4).

Table 4.4 – Regression statistics for data from 1983 to 2013

R-Squared	0.9239	F-Statistic	15.8732
Adjusted R-Squared	0.8657	Probability (F-Statistic)	0.000001
Standard Error of Regressior	23.213	Sum of the Squared Residual	9160.55

Similar to the previous table's results, independent variables with 5 percent significance level are indicated by one asterisk (*) and variables with one percent significance level are indicated by two asterisks (**).

Similar to the first regression, wheat imports indicate a strong linear correlation with wheat prices, but the level of significance has increased to the one percent level. Oil price exhibits a highly significant correlation with wheat prices, as expected, and is consistent with previous regression results. The estimated coefficient for oil prices indicates that an increase in the price of oil by a U.S. dollar is expected to cause a 1.66 dollar increase in the world wheat price if other factors in the regression are held constant. The United States' precipitation level is more significantly correlated in the second estimation, and has a larger estimated coefficient than in the first regression results. Yield in Canada is still correlated with wheat prices at a highly significant level, but with a lower absolute coefficient (-92.03 in the 31-year data regression compared to -129.66 in the 34-year data regression). While this is still an extremely high estimate, the smaller magnitude of the estimated coefficient is more reasonable compared to the estimate found using the entire dataset in the first regression. This indicates that a one millimeter increase in precipitation from the average precipitation level in Canada is associated with a 92.03 dollar decrease in the world wheat price.

Also, the estimated effects of yields in FSU and U.S. on the global wheat price are now statistically significant in the revised specification. The previous year's price is significant at the one percent level, again exhibiting similar results to the first regression that employed the longer, 34-year dataset.

In the second regression, a higher R squared (0.92 compared to 0.81) indicates a better overall representation of the model to explain wheat prices, which is also true of the adjusted R squared (0.87 for the first regression compared to 0.68 for the second regression). This improvement in fit is also indicated in the sum of the squared residual, which is 9160 in the second regression compared to 28900 in the first model. This number indicates the divergence between the data and the estimated model, so a lower number shows a better fit to data for the model.

The difference in results between the first and the second model indicates that there may be unaccounted for effects on world wheat prices in the model specification that limits the ability of the model to describe world wheat prices for the entire timeframe of the analysis. Potential distortions and other factors that are not included in this specification, but may affect the world wheat price, are further discussed in the next chapter.

Import quantities are one of the factors that affect world wheat prices. Summary statistics also show a correlation between wheat import quantities and world wheat price levels. This was expected since imports have direct effects on the world wheat market through shifting the demand curve, and consequently, shifting the market equilibrium to a different price point.

Consistent with studies by Saghaian (2010), Esmaeili (2011), Natanelov et al., (2011), and Chen et al., (2010), oil prices are estimated to affect world wheat prices. This is a reasonable result since wheat production requires fuel for farm machinery as well as inputs that are related to petroleum products. The potential competitive relationship of wheat with energy crops, like maize, for production acreage across a limited land base is another potential reason for this positive correlation.

The effect of precipitation levels on the world wheat price is not meaningful in four of the regions; the exception is in the United States where the estimated coefficient for precipitation is significant. Previous studies including Luo et al. (2005), Valizadeh (2014), Izaurrald et al. (2003) and Zhang and Liu (2005) find significant effects of precipitation on wheat yields. The findings of this thesis may be different when compared to the aforementioned studies due to the scale or scope of research. Those studies investigate a specific region or country in more detail and this might have resulted in more meaningful estimates for the effect of precipitation on the global wheat price. Another reason for this might be the absence of a temperature index in this study that may represent a missing variable since temperature is known to have substantial effects on wheat prices in the higher latitude regions such as Canada and Europe (Kane, 1992).

The estimated coefficients for yield in Canada, FSU and the United States are statistically significant in the second regression, and as expected, yield has a negative effect on world wheat prices. This means that as yield improves, wheat price decreases. Note that growth in yield is not constant in all the regions; for example, in Australia yield fluctuates during the 34-year period and shows an overall weak increase over the full period (Figure 3.2). In general, yield explains wheat price better than precipitation. This might be because yield incorporates the effects of all types of weather fluctuations, including precipitation, temperature, and number of sunny days on wheat production.

Findings regarding the past year's price influence on current year's price were consistent with previous studies. There is a significant correlation between past and current prices, indicating wheat production decisions based on last year's price plays a significant role in determining world wheat price. Chand (2007), Tripathi (2009), and Pashigian (2008) have also noted this lag between the production decisions and its subsequent effects on price. The Cobweb theory also infers that, in markets with such a lag, previous year's and next year's price are correlated and periodic fluctuations in price may occur.

The Chow test was conducted for the second model, and like the first regression, results indicate no breaks at a specified breakpoint of the year 1992. The F-statistic for the Chow test is 0.4497 with a probability of 0.8694 (Appendix 5.2). This means the null hypothesis, that a break point exists in 1992, was rejected at the one and five percent significance levels; so the error terms are normally distributed. Also, the Durbin-Watson d-test shows the value of 2.5422 between d_l and d_u values (Appendix 2.1). These values indicate that, at the five and one percent significance levels, there is no conclusive evidence regarding the presence or absence of positive first order autocorrelation. So, compared to the previous regression, the second model has stronger evidence that autocorrelation is not present in the data.

Comparison of the F-statistic results for the two models shows the group of independent variables jointly have significant effects on the world wheat price and both models fit well.

5. Conclusion

The motivation to conduct this study was to explore the factors that impact wheat prices in the international market, focusing on what may have catalyzed the rapid growth in world wheat prices through 2008, as well as the fluctuations that happened in subsequent years (Figure 2.1). Understanding these factors and how they impact world wheat prices can be useful to economists, market analysts, consulting agencies and government policymakers that consider factors necessary to forecast future market movements, or those who want to consider the welfare impacts if new policies governing trade or production are imposed. To achieve this goal, linear regression analysis was conducted to examine the factors that were assumed to be influential in wheat price determination.

A second regression analysis was employed to improve the fit of the representative model that did not include the data from the early 1980's given market distortions during this timeframe. The economic recession during those years in the United States and other countries' unemployment levels, energy price shocks and corresponding monetary policies throughout the global economy may be possible causes of changes in wheat prices that are not accounted for in the model specification during the early 1980's (Rasche, 1981; Mitchell, 2005; Moy 1985).

Another market distortion in the early 1980's was a U.S. export embargo on trade with the Soviet Union known as the grain trade embargo. With this policy, the United States banned the export of grain and technology to the Soviet Union in response to the invasion of Afghanistan (Hennemuth, 2012). Those restrictions were lifted few years later. As a result, patterns of trade changed while the embargo was in place, and the Soviet Union was faced with import shortages and had to find alternative wheat suppliers. Also, additional domestic market interventions followed in the U.S. due to corresponding decreases in the world wheat price (Luttrell, 1980).

Findings in this study indicate that the important factors that have significant effects on the wheat world price include import quantities, oil prices, precipitation levels in the United States, the previous year’s wheat price and the current year’s yield in Canada, FSU, and the U.S. The linear regression analysis in this thesis explains the factors that affect the world wheat price with a relatively good fit.

Findings demonstrate that import levels have a significant impact on the world wheat price. This becomes evident when we consider the market price as a result of the supply and demand balance. In this study, import quantity is assumed to be representative of the demand side. Many other factors can also influence global demand that are not considered in this study. Future research may focus on the factors that influence import demand and how these factors may affect the world wheat price.

Results show there is a strong relationship between oil and wheat prices; which is consistent with previous studies. A reasonable justification for this linkage may be the fact that wheat production is directly and indirectly affected by oil and energy markets, through both the use of fuel and chemical fertilizers in wheat production, and indirectly, because of management decisions related to biofuel crops that affect the land base dedicated to agricultural production in crops that are produced in the same regions because they do well in certain climates.

In general, results show that precipitation does not have a significant effect on wheat prices, but this finding should be interpreted with caution. Given results shared from earlier research, the insignificance on this variable may be due to missing data on other weather factors that offset the precipitation effects. For instance, in more Northern latitudes, less rain could mean more sunny days or higher temperatures that generally help wheat growth and seed development. Among the five major wheat exporting countries considered, the U.S. is an exception, since precipitation in the state of Kansas is correlated with wheat price at a high significance level. This finding, and the fact that the quantity of U.S. wheat exports is the highest during the time frame considered, suggests that U.S. is a key driver of the global market. But such high and isolated significance for the U.S. precipitation level requires further research to understand what other factors may be involved in this correlation and to more carefully compare with other regions that do not exhibit such a relationship.

This study looks at the relationship between precipitation in exporting regions and wheat prices, whereas precipitation can also affect price from the demand side of any global equilibrium. For example, precipitation in wheat importing countries could affect wheat prices by changing the balance between imports, production and consumption levels in these countries. Because the quantity of wheat imported has a significant effect on world wheat prices, this is another result that justifies further exploration.

Contrary to the results on precipitation, the findings for yields show a stronger effect on wheat prices. In general, there is a negative relationship between yield and the world wheat price. There were exceptions in the results for Australia and for the European Union. For Australia, the estimated coefficient for yield is negative, as expected, but insignificant. On the other hand, the estimated coefficient for E.U.'s wheat yield is positive, but insignificant. Since yield has had a constant gradual increase during the timeframe considered in all regions, except for in Australia where yields fluctuated, especially after the year 2000 (Figure 4.5), this may explain the insignificance of the estimate for the effect of yield in Australia on world wheat prices.

Although the European Union is the second largest exporting region (when considering export volumes) during the timeframe studied, the yields reported from E.U. (represented by the North and Central regions of France) shows no significant effect on the world wheat price. This insignificant result may be because the yield data reported are for only one region of France, which is a small subset of the total area in the E.U. involved in wheat production and exports. Further research is required to understand why E.U. yields and world wheat prices have an insignificant relationship in the model estimated.

As explained in the previous chapter, the previous year's price is expected to have a significant effect on the subsequent year's wheat price. Production of agricultural commodities has a natural lag between supply and demand decisions. In fact, the previous year's price incorporates effects of other factors influencing the wheat market during the previous year, and is broadly representative of the market. Factors like substitute crop markets can also influence wheat production decisions, and since those relationships are fairly consistent, the previous year's price may be a proxy for persistence in such factors.

This study has many limitations; climate change is a very complex phenomenon and is not represented completely with the simple economic model employed in this study. This deficiency becomes more significant in a study over a long term period. Moreover, other factors affecting wheat markets and changes in the global economy make economic modeling of wheat prices challenging. This study simplifies the real world market and investigates the relationship between the key factors that affect the wheat price at the global level using key economic principles and climatic information. Beside the inherent limitations of the economic model, lack of accessibility to historical data from different countries also limits the extent and accuracy of this study. Variations in data collection are another drawback of this research. For example, weather station locations have changed during the time frame, which limited access to weather data for the timeframe studied.

Understanding how environmental and economic factors affect wheat prices can help international organizations and governments better understand market dynamics. In an era of great concern about food security, such analysis allows leaders to plan more effectively and prepare to face potential future shortages or fluctuations that may result from weather changes or market shocks. Besides, recognizing how all countries interact in the global wheat market may lead to a better understanding of international trade in wheat that may be tied to production and other factors affecting trade.

Future studies of the wheat market at the global scale will require cooperation of globally-focused researchers to compile more detailed information and conduct rigorous market analyses of both supply and demand factors in the world wheat market. In this research, demand factors beyond import quantities were not investigated, but may be important to consider for future research. Future studies that investigate the factors affecting both exporting and importing countries with more detail would be a valuable contribution to the literature.

6. References

1.Ackello-Ogutu, C. (1997). *Unrecorded Cross-Border Trade Between Kenya and Uganda Implications for Food Security.* SD Publication Series Office of Sustainable Development Bureau for Africa, USAID. Technical Paper No. 59 (July 1997)

2.AGDA (Australian Government Department of Agriculture), (2015). *Wheat Overview*. Retrieve from: http://www.agriculture.gov.au/ag-farm-food/crops/wheat

3.Aksoy, M. A. and Beghin, J. C. (2005). *Global Agricultural Trade and Developing Countries*. The International Bank for Reconstruction and Development. The World Bank. (2005) pp. 195-214.

4.Asseng, S., Foster; and Turner (2010). *The impact of temperature variability on wheat yields*. Global Change Biology, (2011).Volume 17 pp. 997–1012.

5.Australia grain yearbook (2008). Australia Bureau of Statistics. Domestic Wheat. pp. 30-32. Retrieve from: http://goo.gl/xQOT1q

6.Bobenrieth, E., Wright, B., and Zeng, D., (2012). *Stocks-to-use ratios and prices as indicators of vulnerability to spikes in global cereal markets*. Agricultural Economics, (2013). Volume 44, supplement 43-52

7.Brisson, et al., (2010). *Why are wheat yields stagnating in Europe? A comprehensive data analysis for France.* Field Crops Research. Volume 119, Issue 1, (October 2010). pp. 201–212

8.Bureau of Labor Statistics (2015). *Overview of BLS Statistics on Inflation and Prices,* Consumer Price Index. Retrieve from: http://www.bls.gov/cpi/

9.Chakraborty, S. and Newton, A. C. (2011). *Climate change, plant diseases and food security: an overview*. Plant Pathology (January 2011), issue 60, pp. 2–14

10. Chand, R. (2007). *Wheat Supply, Price Prospects, and Food Security*. Economic and Political Weekly, Vol. 42, No. 19 (May 12-18, 2007), pp. 1659-1663.

11. Chen et al., (2010). *Modeling the relationship between the oil price and global food prices.* Applied Energy. Volume 87, Issue 8, (August 2010). pp. 2517–2525.

12. Curtis, Rajaraman, MacPherson (2002). "Bread Wheat." Food and Agriculture Organization of the United Nations.

13. Dai, A. (2011). *Drought under global warming: a review*. WIREs Climate Change, 2: pp. 45–65. doi: 10.1002/wcc.81

14. Daugherty, K., and Kelly, K., (2014). *Stocks and the Stocks-to-Use Ratio: Are They Meaningful for Price Determination?* GROWMARK Research (June 2014). pp. 1-32. Retrieve from: http://www.growmark.com/sites/Files/Documents/StocksToUse.pdf

15. Dorosh, A. Paul, et al (2002).*Price Responsiveness of Food grain Supply in Bangladesh and Projections 2020*. The Bangladesh Development Studies. Volume. 28, No. 1/2 (March-June 2002) , pp. 47-75

16. EIA (United States Energy Information Administration), (2015). Petroleum and Other Liquids. Retrieve from: http://www.eia.gov/petroleum/data.

17. ERS- USDA report (2015). *Wheat year book table 3*. USDA, Foreign Agricultural service, production, Supply and Distribution Database. Retrieve from: http://www.ers.usda.gov/datafiles/Wheat_Wheat_Data/Yearbook_Tables/World_Production_Supply_and_Disappearance/WheatYearbookTable03Full.xls

18. Esmaeili, A., and Shokoohi, Z., (2011). *Assessing the effect of oil price on world food prices: Application of principal component analysis*. Energy Policy. Volume 39, Issue 2, (February 2011). pp. 1022–1025
19. FAO (Food and Agriculture Organization of the United Nations) Statistics (2014-15). Retrieve form: http://faostat3.fao.org/browse/T/*/E
20. Frieden, A. J. and Rogowski, R. (1996). *The Impact of the International Economy on National Policies: An Analytical Overview*. Internationalization and Domestic Politics. (1996) Cambridge University Press. pp. 25-47
21. Foreign Agricultural Services USDA (2014). Grain World Markets and Trade. World Production, Markets, and Trade Reports. Retrieve from: http://www.fas.usda.gov/data/grain-world-markets-and-trade
22. Hennemuth, L., (2012). 1980 U.S. Partial Grain Embargo: Pragmatism's Centrality to Argentine Refusal to Cooperate. The Monitor (Summer 2012). pp. 44-55
23. Hertel, T. W. et al. (2010). *Potential Implications of a Special Safeguard Mechanism in the World Trade Organization: the Case of Wheat.* The World Bank Economic Review. doi: 10.1093/Weber/lhq010. (August 2010)
24. Izaurralde, R. C., et al (2003). *Integrated assessment of Hadley Center (HadCM2) climate-change impacts on agricultural productivity and irrigation water supply in the conterminous United States Part II. Regional agricultural production in 2030 and 2095*. Agricultural and Forest Meteorology 117 (2003) pp. 97–122
25. Jebabli, I., et al (2014). *On the effects of world stock market and oil price shocks on food prices: An empirical investigation based on TVP-VAR models with stochastic volatility*. Energy Economics. Volume 45, (September 2014), pp. 66–98

26. Leonard, W.H., and Martin, J.H. (1963). *Wheat: Importance, history and adaptation*. In W.H. Leonard and J.H. Martin (ed.) Cereal crops. Macmillan Co., New York. pp. 277-287.
27. Liverman, M. D. (1987). *Forecasting The Impact Of Climate On Food Systems: Model Testing And Model Linkage*. Climate change 11 (1987) pp. 267-285
28. Luo, et al. (2005). *Potential impact of climate change on wheat yield in South Australia*. Agricultural and Forest Meteorology 132 (2005) pp. 273–285
29. Luttrell, B. C. (1980). *The Russian Grain Embargo: Dubious Success*. Federal Reserve Bank of St. Louis (August 1980).
30. McCalla, F. A. (2009). *World Food Prices: Causes and Consequences*. Canadian Journal of Agricultural Economics 57 (2009) pp. 23–34
31. Meza, J. Francisco, and Silva, D. (2009). *Dynamic adaptation of maize and wheat production to climate change*. Climatic Change (2009) Vol. 94, Issue 1-2, pp. 143–156
32. Mitchell, O. Donald, and Mielke, Myles. (2005) *Wheat: The Global Market, Policies, and Priorities*. Global Agricultural Trade and Developing Countries, World Bank, (2005). pp. 195-214
33. Natanelov, V., et al (2011). *Is there co-movement of agricultural commodities futures prices and crude oil?* Energy Policy. Volume 39, Issue 9, (September 2011), pp. 4971-4984
34. NOAA 2015, NOAA (National Oceanic and Atmospheric Administration) web site, 2015. http://www.cdc.noaa.gov/ENSO/enso.mei_index.html.
35. Nuttonson, M. Y. (1955). *Wheat-climate relationships and the use of phenology in ascertaining the thermal and photo-thermal requirements of wheat*, Washington: American Institute of Crop Ecology, 1955, pp. 10-11.

36. OECD (Organization for Economic Co-operation and Development) -FAO, (2015). Agricultural Outlook 2014-2023 Food and Agriculture Organization of United Nation. Retrieve from: http://goo.gl/DHK14Y
37. Ortiz, et al. (2008). *Climate change: Can wheat beat the heat?* Agriculture, Ecosystems and Environment 126 (2008) pp. 46–58
38. Pashigian, B. Peter. (2008) "cobweb theorem." The New Palgrave Dictionary of Economics. Second Edition. Eds.
39. Rogers, H. Danny. (1997). *Irrigation Management*. Wheat Production Handbook. Manhattan, Kansas State University. Cooperative Extension Publication C-529 (May 1997)
40. Sadorsky, P. (2014). *Modeling volatility and correlations between emerging market stock prices and the prices of copper, oil and wheat*. Energy Economics. Volume 43, (May 2014), pp. 72–81
41. Saghaian, H. Sayed (2010). *The Impact of the Oil Sector on Commodity Prices: Correlation or Causation?* Journal of Agricultural and Applied Economics, 42,3 (August 2010) pp. 477–485
42. Sekhar, C.S.C. (2003). *Price formation in world wheat markets — implications for policy*. Journal of Policy Modeling. Volume 25, Issue 1 (January 2003), pp. 85–106
43. Shend, Y. Jaclyn, (1993). *Agricultural Statistics of the Former USSR Republics and the Baltic States*. Statistical Bulletin Number 863, ERS, USDA, (September 1993)
44. Sivakumar, M. V. K. (2005). *Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi-arid tropics*. Climate change (2005). pp. 31-72

45. The World Bank, (2014). Cereal Yield Data. World Development Indicators: Agricultural output and productivity. Retrieve from: http://data.worldbank.org/indicator/AG.YLD.CREL.KG/countries

46. Tripathi, A.K. (2009). *Understanding the Price-Production Puzzles in the Indian economy*. The Journal of income and wealth, Vol. 31, No. 2, June-December, 2009

47. Ubilava, D. (2014). *International Wheat Price Responses to ENSO Shocks: Modelling Transmissions Using Smooth Transitions*. Social Science Research Network, (August 2014). At: http://ssrn.com/abstract=2477672

48. USDA (United States Department of Agriculture), (2014). Economic Research Services. Retrieve from: http://www.ers.usda.gov/topics/crops/wheat/trade.aspx#

49. Valizadeh, J. et al., (2014) *Assessing climate change impacts on wheat production*. Journal of the Saudi Society of Agricultural Sciences. Volume 13, Issue 2, (June 2014), pp. 107–115

50. VOA, (2013). *US Seeks Fast Test to Settle GM Wheat Scare*. Voice of America. Science and Technology. (June 4, 2013.)

51. World Wheat Crop, *To Be Third Largest Ever*. Farmers Weekly 152.13 (2010): 134. Academic Search Premier. Web. 13 March 2013.

52. Year Book Australia, (2006). *The Australian Wheat Industry*. 1301.0 year book Australia, (2006). Retrieve from: http://goo.gl/Y7jKjc

53. Zhang, X.C., and Liu, W.Z. (2005). *Simulating potential response of hydrology, soil erosion, and crop productivity to climate change in Changwu tableland region on the Loess Plateau of China*. Agricultural and Forest Meteorology. 131 (2005) pp. 127–142

7. Appendix

1.

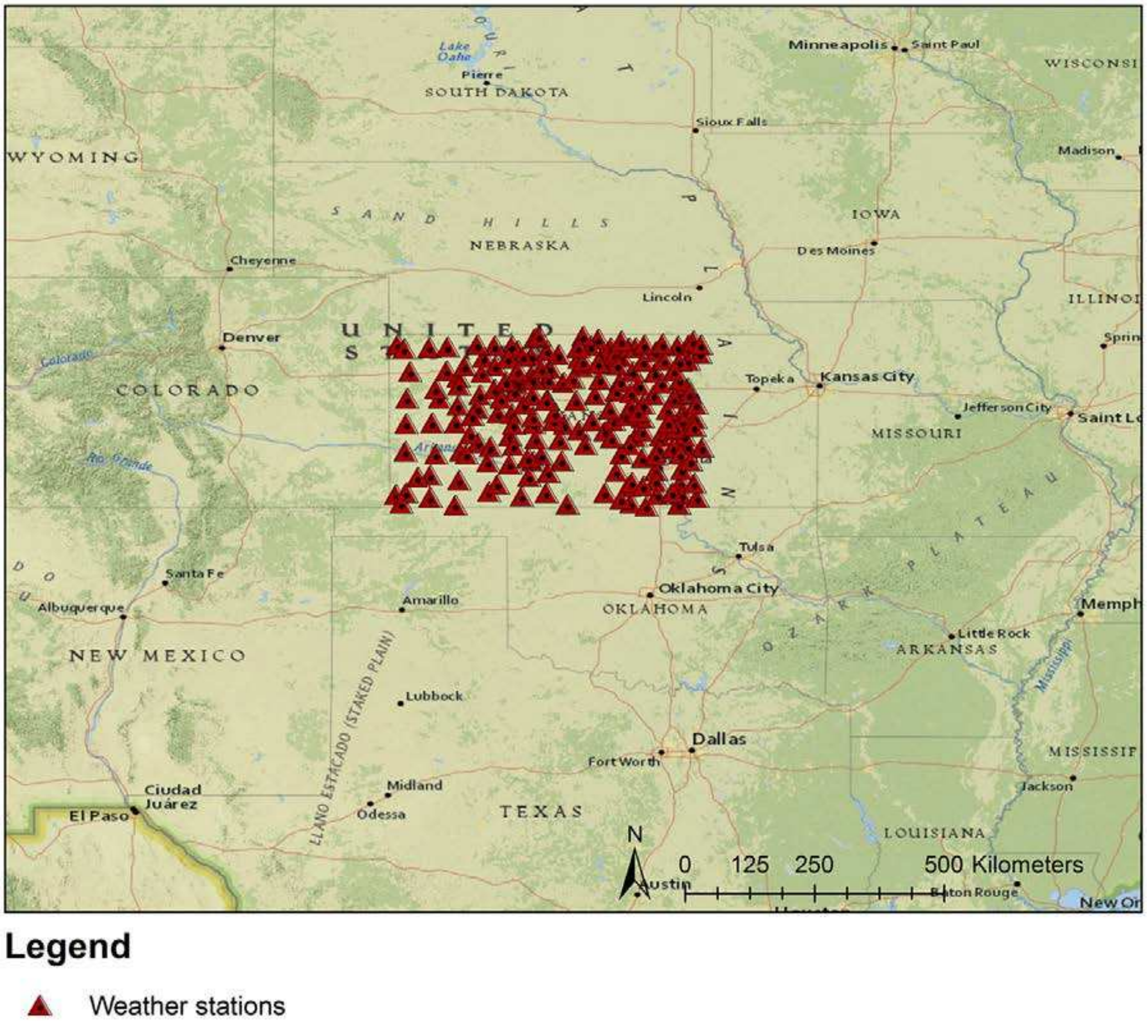


Figure A.1.1. Kansas state weather stations

Kansas state with the highest wheat production for a state within this country, was selected as a precipitation indicator for the United States. Geographic Information System (GIS) software was used to select specific data related to Kansas. Weather stations that have been active for all or most of 34 year time-frame are considered. Each triangle represents one weather station in the map.

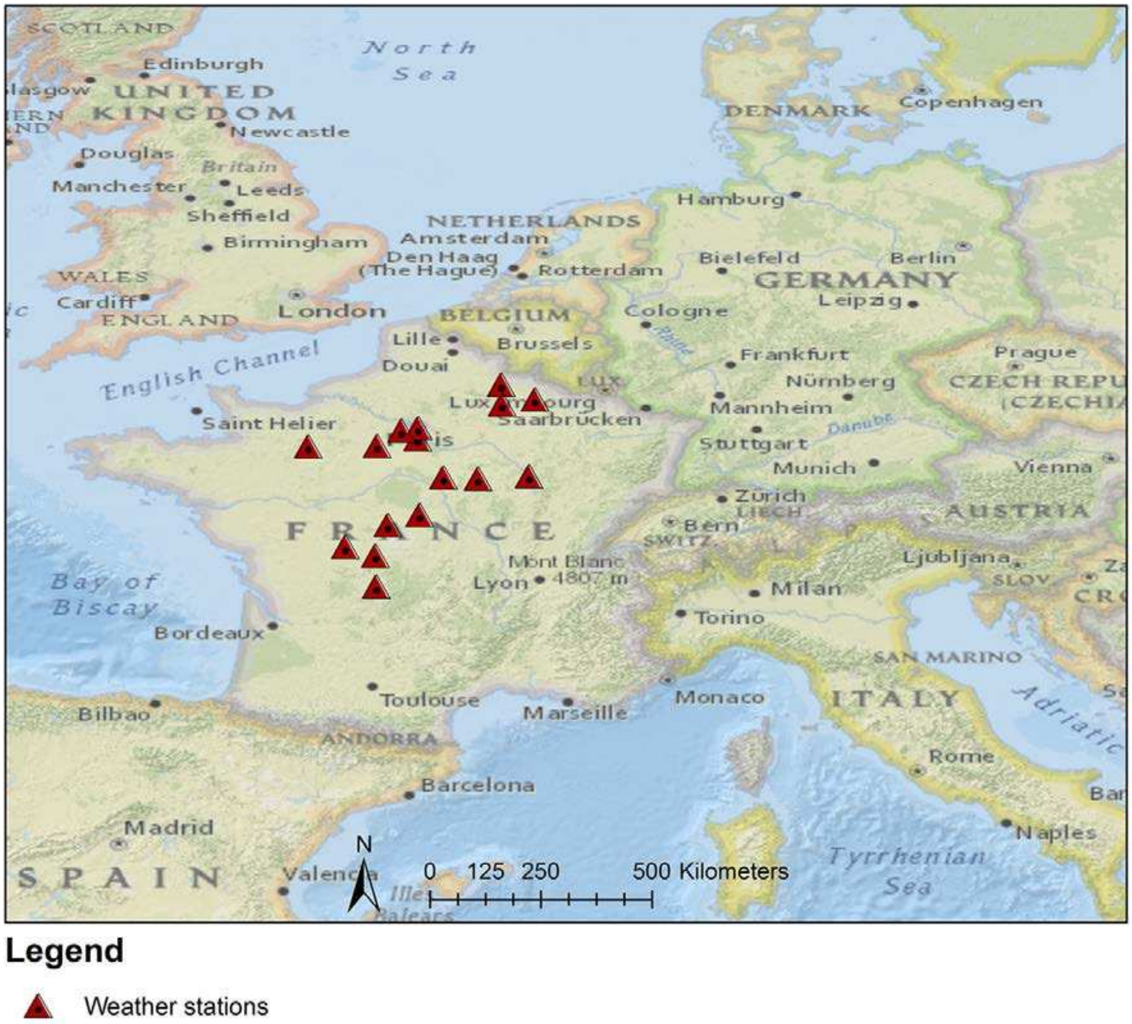


Figure A.1.2. France weather stations

France was selected as a precipitation indicator for the European Union. Geographic Information System (GIS) software was used to select weather data related to France. Weather stations that have been active for all or most of 34 year time-frame are considered. Each triangle represents one weather station in the map. Not many stations were active in France during time-frame.

Figure A.1.3. Saskatchewan weather stations

Saskatchewan was selected as a precipitation indicator for Canada because it reported the highest wheat production for that country. Geographic Information System (GIS) software was used to select weather data related to Saskatchewan. Weather stations that have been active for all or most of 34 year time-frame are considered. Each triangle represents one weather station in the map.

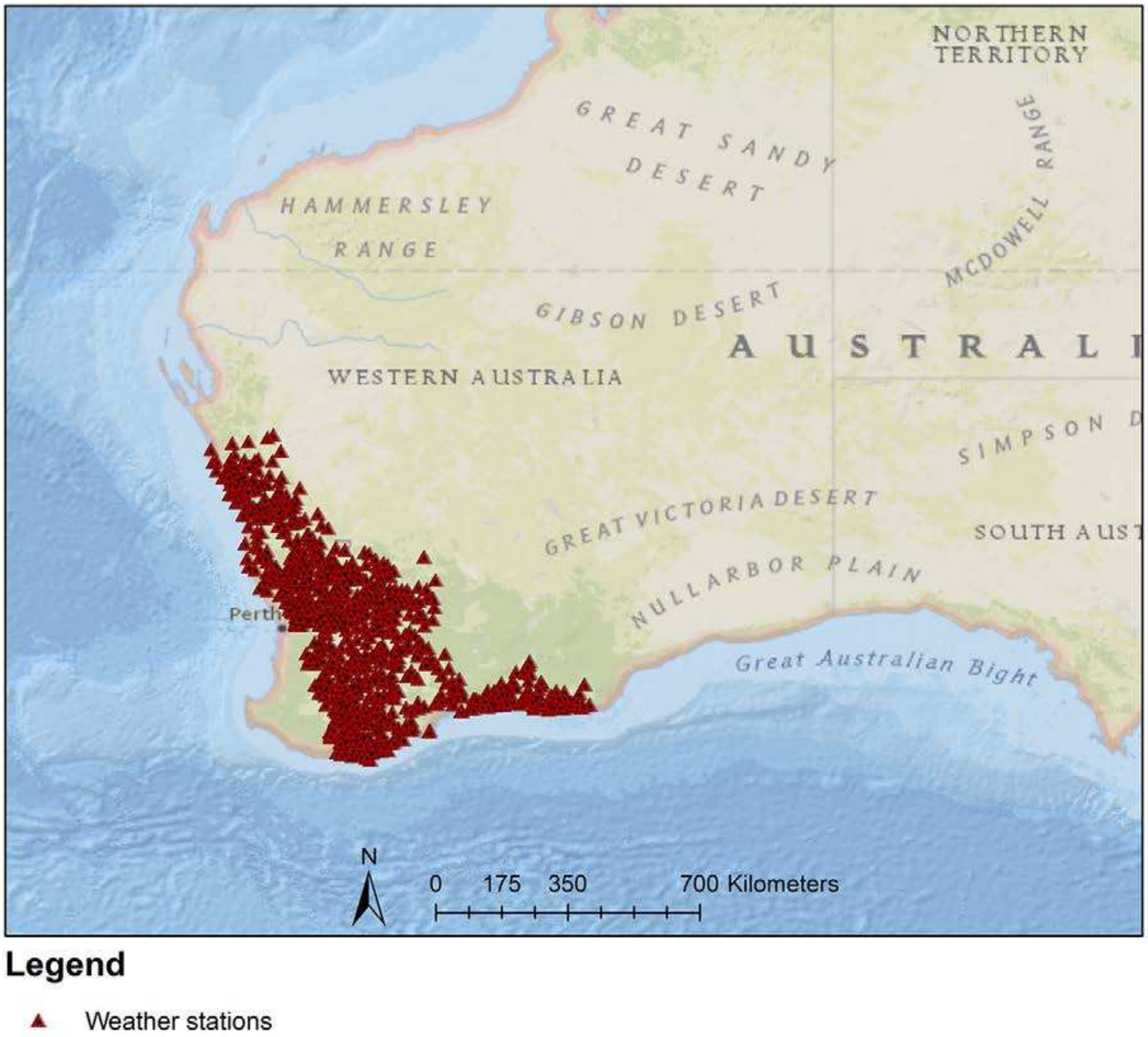


Figure A.1.4. Western Australia weather stations

Western Australia was selected as a precipitation indicator for Australia. Geographic Information System (GIS) software was used to select weather data related to Western Australia. Weather stations that have been active for all or most of 34 year time-frame are considered. Each triangle represents one weather station in the map. Australia has the lowest precipitation compare with other regions/countries.

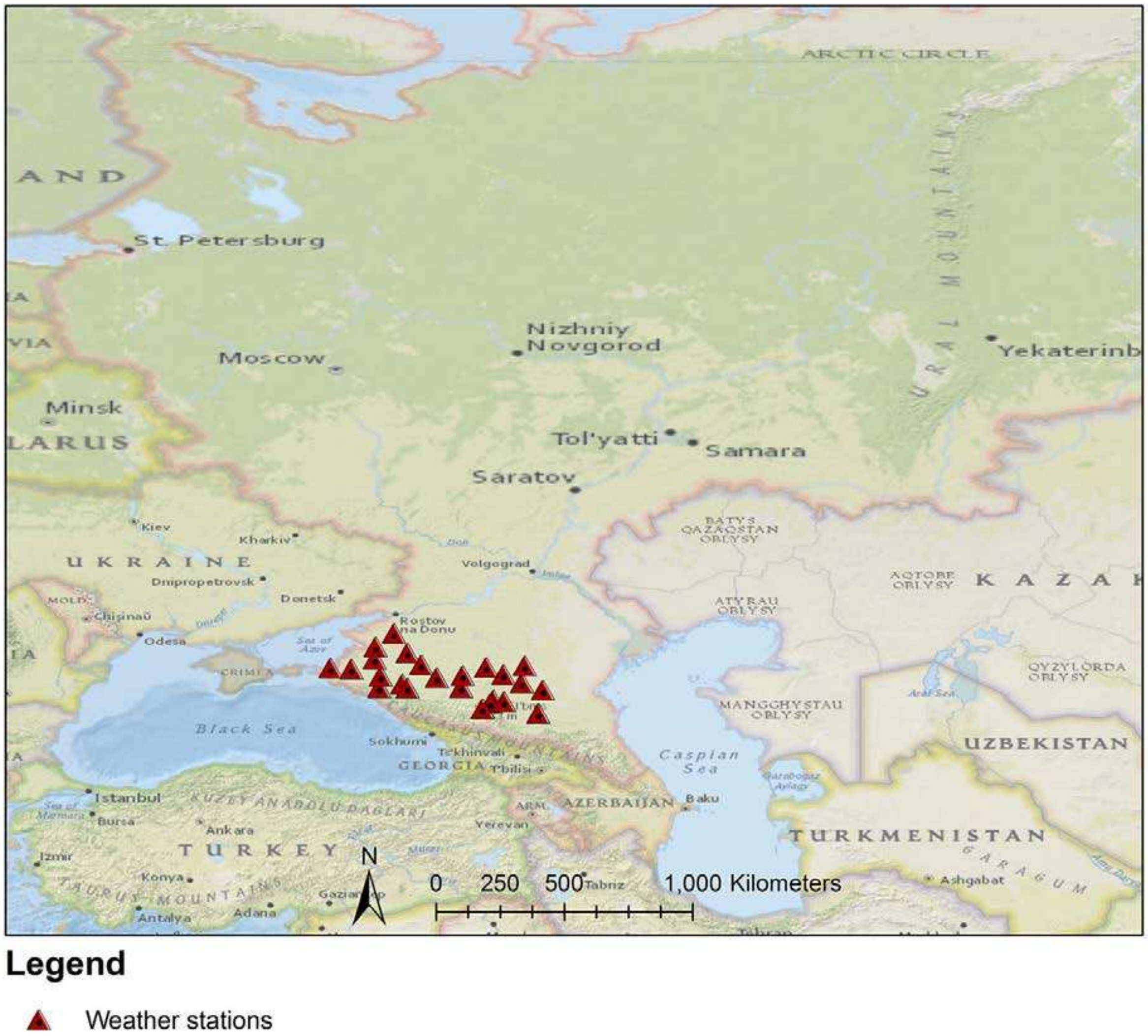


Figure A.1.5. Krasnodar & Stavropol weather stations

Krasnodar & Stavropol (Southern Russia) was the region selected as a precipitation indicator for the Former Soviet Union (FSU). Geographic Information System (GIS) software was used to select weather data related to Krasnodar & Stavropol. Weather stations that have been active for all or most of 34 year time-frame are considered. Each triangle represents one weather station in the map.

2.

Table A.2.1. Eviews software results for 31 years observation

A second ordinary least square test was conducted to find correlation between the dependent variable (wheat price) and independent variables within the new time frame

Dependent Variable: WPRICE
Method: Least Squares
Included observations: 31

Variable	Coefficient	Std. Error	t-Statistic	Prob.
IMPORT	2.061483	0.638864	3.226796	0.0050
OIL_PRICE	1.662027	0.448376	3.706770	0.0018
AUSTRALIA	-0.090974	0.061945	-1.468622	0.1602
CANADA	0.049098	0.039647	1.238381	0.2324
EU	0.044846	0.032154	1.394760	0.1810
FSU	-0.027897	0.028746	-0.970480	0.3454
US	0.103204	0.021362	4.831141	0.0002
YAUSTRALIA	-10.70021	20.96781	-0.510316	0.6164
YCANADA	-92.03408	26.78467	-3.436073	0.0032
YEU	32.39213	21.57620	1.501290	0.1516
YFSU	-105.3466	22.89093	-4.602109	0.0003
YUS	-98.20620	46.25467	-2.123163	0.0487
P_T_1_	0.426882	0.127242	3.354894	0.0038
C	350.8070	95.21390	3.684410	0.0018

R-squared	0.923887	Mean dependent var	246.2096
Adjusted R-squared	0.865682	S.D. dependent var	63.33878
S.E. of regression	23.21326	Akaike info criterion	9.429777
Sum squared resid	9160.545	Schwarz criterion	10.07738
Log likelihood	-132.1615	Hannan-Quinn criter.	9.640880
F-statistic	15.87317	Durbin-Watson stat	2.542201
Prob(F-statistic)	0.000001		

Table A.2.2. Eviews software results for 34 years observation

The Ordinary least square test was conducted to test for potential correlation between dependent variable (wheat price) and independent variables during the 1980 to 2013 period

Dependent Variable: WPRICE
Method: Least Squares
Included observations: 34

Variable	Coefficient	Std. Error	t-Statistic	Prob.
IMPORT	2.187313	1.031447	2.120626	0.0466
OIL_PRICE	0.924993	0.702979	1.315820	0.2031
AUSTRALIA	0.013149	0.096284	0.136563	0.8927
CANADA	0.083467	0.063196	1.320757	0.2015
EU	0.032244	0.048633	0.662995	0.5149
FSU	-0.049245	0.046670	-1.055176	0.3039
US	0.070335	0.033344	2.109350	0.0477
YAUSTRALIA	-3.534340	31.21367	-0.113231	0.9110
YCANADA	-129.6632	42.51857	-3.049566	0.0063
YEU	59.68493	31.63549	1.886645	0.0738
YRUSSIA	-59.45542	34.96255	-1.700546	0.1045
YUS	-60.04341	73.23204	-0.819906	0.4219
P_T_1_	0.514747	0.185631	2.772952	0.0117
C	104.6386	136.4058	0.767112	0.4520

R-squared	0.807205	Mean dependent var	252.6195
Adjusted R-squared	0.681888	S.D. dependent var	67.39768
S.E. of regression	38.01326	Akaike info criterion	10.40665
Sum squared resid	28900.16	Schwarz criterion	11.03515
Log likelihood	-162.9130	Hannan-Quinn criter.	10.62099
F-statistic	6.441306	Durbin-Watson stat	1.574608
Prob(F-statistic)	0.000123		

3.

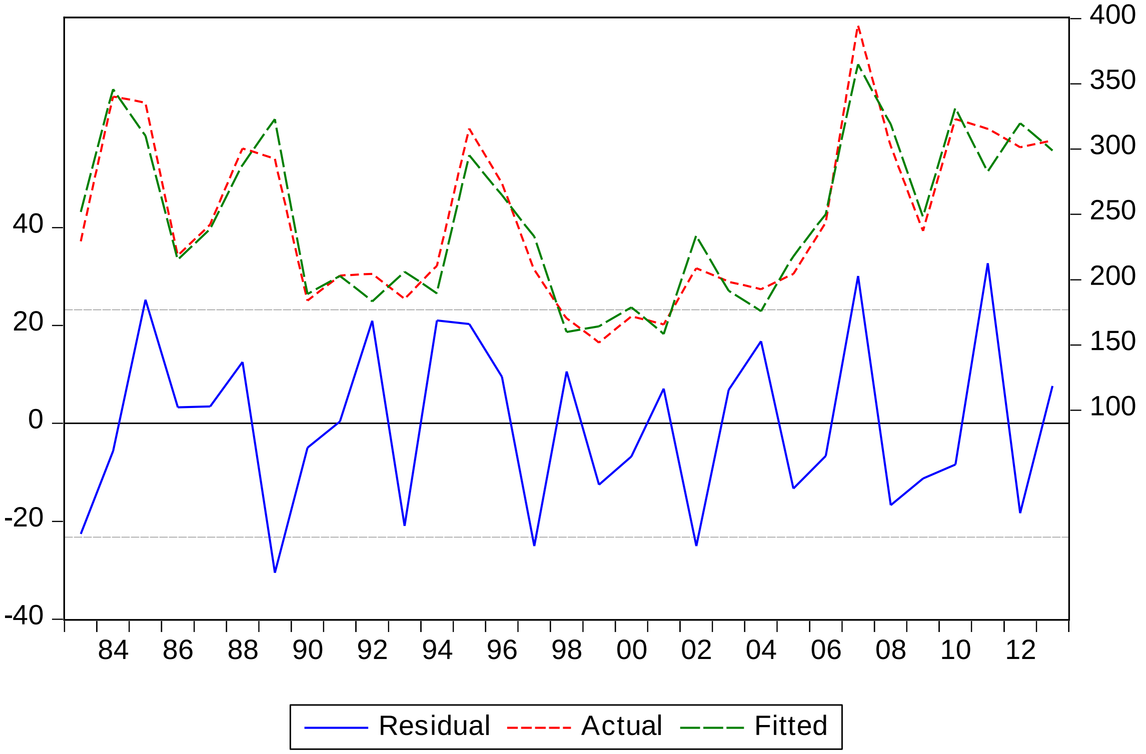


Figure A.3.1 World wheat price analyses including second regression Actual prices, Fitted prices, and Residuals

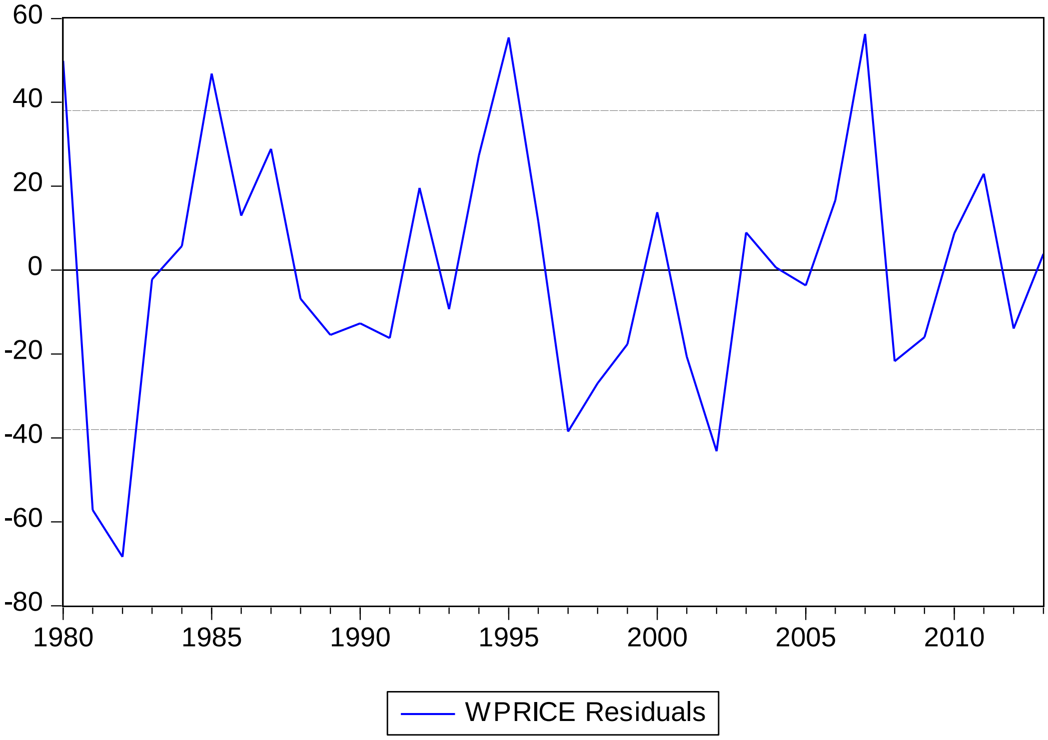


Figure A.3.2. World wheat price regression residual graph, all 34 years

The residuals for the 1980, 1981, and 1982 periods were found to be significantly larger and therefore a second regression was conducted on the data including the period of 1983 to 2013.

4.

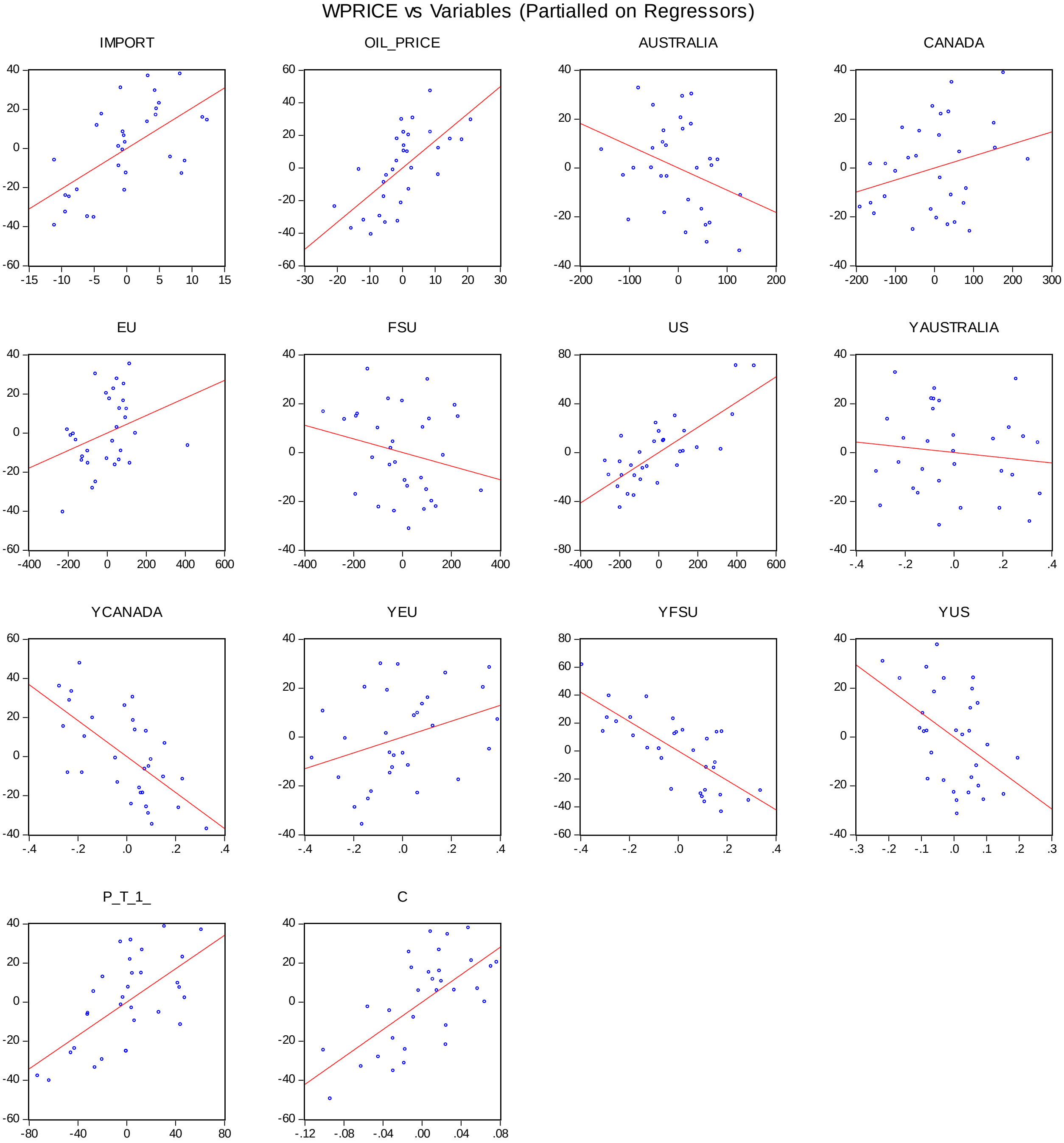


Figure A.4.1 World wheat price regressed on variables in the second equation. Y= Yield, P_T_1= Last year price,

5.

Table A.5.1 Chow test results for 34 year period (1980-2013)

Chow Breakpoint Test: 1992
Null Hypothesis: No breaks at specified breakpoints
Varying regressors: All equation variables
Equation Sample: 1980 2013

F-statistic	2.699271	Prob. F(14,6)	0.0831
Log likelihood ratio	64.45146	Prob. Chi-Square(14)	0.0000
Wald Statistic	33.94049	Prob. Chi-Square(14)	0.0021

Table A.5.2 Chow test results for 31 year period (1983-2013)

Chow Breakpoint Test: 1992
Null Hypothesis: No breaks at specified breakpoints
Varying regressors: All equation variables
Equation Sample: 1983 2013

F-statistic	0.449678	Prob. F(14,3)	0.8694
Log likelihood ratio	35.05842	Prob. Chi-Square(14)	0.0014
Wald Statistic	6.295487	Prob. Chi-Square(14)	0.9585